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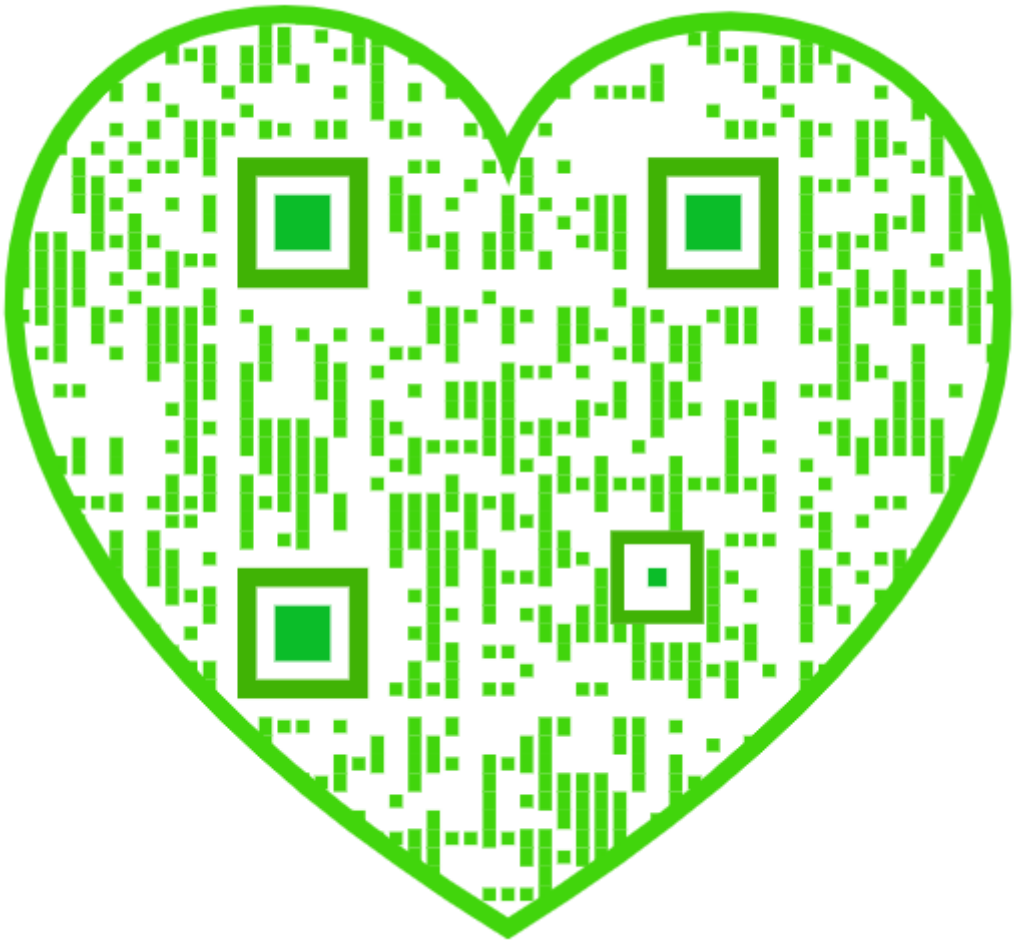

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LABORATORY AND FIELD EXERCISES

FOR "GENERAL BOTANY"

BY

HIRAM D. DENSMORE

PROFESSOR OF BOTANY AT BELOIT COLLEGE

GINN AND COMPANY

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PREFACE

These laboratory and field exercises have been written to accompany the author's textbook in general botany, and the topics for the practical exercises are therefore arranged in the same order as in the text.

Both the textbook and the exercises have been used with several generations of students and instructors, whose criticisms and suggestions are embodied in this revision of the field and laboratory exercises for publication. The topics in the practical exercises also follow those of the text and are divided into three more or less distinct parts.

Part I contains directions for some field work, laboratory work, and experiments on the general form, structure, and physiology of the higher green plants.

Part II is devoted to practical laboratory exercises relating to the general morphology and relationship of the great plant groups, from the algæ and fungi to the highest seed plants. The laboratory exercises on anatomy in Part II are designed to enable teachers not familiar with the methods of the new anatomy to direct students in the study of plant structure from the more modern standpoint. It is hoped that the diagrams and discussions of the text on anatomy will materially assist both teachers and students in making the exercises clear.

Part III contains directions for field work on trees, shrubs, and herbaceous plants, considered from a general ecological standpoint. A brief study of plant associations has been added, in order to introduce the student to the study of plants in their social relations. Emphasis is also laid, in the exercises as in

the textbook, on the study of plants as living organisms, closely related and adapted to the environment at all seasons of the year. The few species selected for field study are taken from families represented in the spring flora which are of special biological or economic interest. No attempt has been made to outline practical studies for all important families of the spring flora, since only a limited number of species could be studied in an introductory course in college botany.

Although these exercises have been written to accompany the author's textbook, they can easily be adapted for use with any text, or to accompany lectures in an introductory course in botany or plant biology.

CONTENTS

PART I. BIOLOGY OF THE HIGHER SEED PLANTS

SECTION I. PLANTS AND THE ENVIRONMENT

PAGE

A. The Body Plan and Form of Plants 3

The Lilac 3

Herbaceous Plants 6

Trees (Spruces and Pines) 9

Trees (the American Elm) 13

B. Adjustment to the Environment 18

The Embryo and Seedling of the Bean 18

Experiments 20

Supplementary Studies 21

SECTION II. CELL STRUCTURE AND GROWTH

A. The Cellular Structure of Plants 22

Cell-Wall Thickening and Cell Differentiation 24

Protoplasm, Vacuoles, and Nuclei in Root-Tip Cells . . . 26

Cell Structure and Protoplasmic Streaming in Stamen Hairs of *Tradescantia* 27

Plastids in Plant Cells 30

B. Cell Structure and Growth 31

Growth 31

C. The Cell and Cell Division 35

Supplementary Studies 39

SECTION III. ANATOMY

PAGE

A. Anatomy of Stems 41
External Features of Woody Stems 41
Gross Structure of Mature Stems 42
Microscopic Structure of Woody Stems 45
Herbaceous Stems (Dicotyledons) 50
Herbaceous Stems (Monocotyledons) 52
B. Structure of Roots 53
C. The Structure of the Leaf 53

SECTION IV. PHYSIOLOGY OF PLANTS

A. Photosynthesis 57
B. Respiration 60
C. Transpiration and Water Ascent 61

SECTION V. REPRODUCTION

A. Sexual Reproduction 64
The Flower and its Parts 64
Pollination in Papilionaceous Flowers 68
Structure of Papilionaceous Flowers 69

PART II. THE PLANT GROUPS

SECTION VI. THALLOPHYTES (ALGÆ AND FUNGI)

A. The Algæ 75
Protococcus (*Pleurococcus*) 75
Chlamydomonas 76
Spirogyra 77
Vaucheria 79
Œdogonium 81
General Study of Fresh-Water Algæ 82
Fucus vesiculosus 83

PAGE

B. The Fungi 86
Yeast 86
Bacteria 89
Molds 92
Mushrooms and their Allies 97
Mushrooms and their Allies (Rusts and Smuts) 100
Lichens 101
Lilac Mildew 102

SECTION VII. *BRYOPHYTA* (LIVERWORTS AND MOSSES)

A. Hepaticæ (Liverworts) 103
B. Musci (Mosses) 108

SECTION VIII. *PTERIDOPHYTA* (FERNS, EQUISETA, AND LYCOPODS)

A. Filicales (True Ferns) 113
B. Equisetales (Horsetails) 123
C. Lycopodiales (Club Mosses) 126
Lycopodium 126
Selaginella 127

SECTION IX. GYMNOSPERMS

A. Cycadales (Cycads) 130
B. Coniferales (Spruces and Pines) 135

SECTION X. ANGIOSPERMS (DICOTYLEDONS)

Sporophyte 143
Capsella (Shepherd's Purse) 149

PART III. THE SPRING FLORA

SECTION XI. FIELD WORK (DICOTYLEDONS)

A. Trees and Shrubs 155
A Method of recording Field Observations 155

PAGE

Gymnosperms (Softwood Trees) 159
Angiosperms (Hardwood Trees) 161

B. Herbaceous Dicotyledons 167
A Method of recording Field Observations 167
Ranunculaceae 171
Violaceae 173
Cruciferae 175
Leguminosae 177
Rosaceae 179
Compositae 181

SECTION XII. FIELD WORK (MONOCOTYLEDONS)

A. Tradescantia, Tulip, and Other Monocotyledons . . 185
B. Solomon's Seal (*Polygonatum* and *Smilacina*) . . . 188
C. Iridaceae and *Araceae* 190
D. Gramineae 191

SECTION XIII. PLANT ASSOCIATIONS

Nature and Composition of Plant Associations 192
Kinds of Associations 194
Origin of New Associations 195

INDEX 197

LABORATORY AND FIELD EXERCISES FOR "GENERAL BOTANY"

PART I. BIOLOGY OF THE HIGHER SEED PLANTS

SECTION I. PLANTS AND THE ENVIRONMENT

A. THE BODY PLAN AND FORM OF PLANTS

THE LILAC

1. **Leaves.** Do the leaves spring from definite points on the axis of the main stem and its branches, or are they irregularly arranged? Are they cyclic (two or more leaves attached at the same level) or spiral in arrangement? Are the leaves so placed as to give the maximum light to each leaf? Observe the shoot from above. How many rows of leaves are there along the stem? Be able to explain the light relations of the leaves. Consult Figs. 5 and 6 of the text.[1]
2. **Buds and branches.** How are the buds related to the leaves as regards position and arrangement on the stem and branches? Is there a terminal bud in the lilac? Do the branches have the same orderly arrangement as the buds and leaves? Why? Do branches grow from buds?
3. **Stem divisions.** Is the stem divided into regular divisions by the origin of leaves, buds, and branches from definite points? Consult the text under The Form and Plan of the Plant Body concerning the nature and relation of nodes and internodes.

   a. Sketch an entire shoot of a lilac in outline to show the orderly plan upon which it is constructed. Remove the leaves on the side of the branch facing you and

[1] All text references are to Densmore's "General Botany."

indicate their position by drawing the scars left by their removal. Note the bud above the scar, formerly in the axil of the leaf.

b. Read text on The Form and Plan of the Plant Body. Label all the parts of the finished drawing correctly. Name the buds on the basis of position, that is, terminal or lateral. Consult Figs. 38 and 45 of text.

4. **The structure and growth of buds.**

a. Plan of the bud. Observe the external surface of the largest buds on your specimen. Use hand lens for details. Have the parts of the bud a definite arrangement? Is this arrangement the same as that of leaves on the main stem? Separate the parts of the bud carefully and observe their origin and arrangement. Is there a central axis to

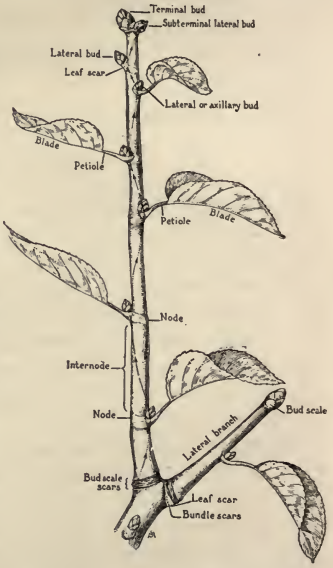

FIG. 1. Parts of a shoot with a spiral body plan

The diagram represents a single year's growth of a woody shoot. The bud-scale scars mark the lower limit of the year's growth

which the parts are attached? This point can be demonstrated by bisecting the bud. See Fig. 2, and Fig. 37 (p. 68) of the text.

b. Sketch the external surface of a bud and label its parts.

c. *Growth of buds.* Do all of the buds in the axils of the leaves grow each season? Examine older portions of the branch to determine this point. Are the branches produced each season of the same length and vigor? Note the forked branching due to the growth of the two vigorous subterminal lateral buds. Can you determine the age of the branch you are studying? Look for the scars left by the bud scales each season (Fig. 1, and Fig. 38 of the text).

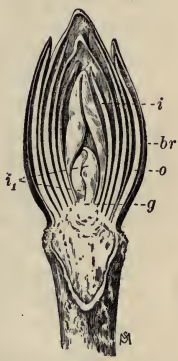

FIG. 2. Vertical section of a hawthorn bud

br and *o*, outer and inner bud scales; *i*, i_1, outer and inner leaves; *g*, growing point, or meristem, of the bud. From Bergen and Caldwell's "Practical Botany"

5. **The shrubby form of the lilac.** Study the form of the branch with which you are working, as well as that of lilac shrubs in the field. Is the rounded, shrubby habit of the lilac due to the arrangement and method of bud growth? For example, suppose the lilac shoots had a single continuous terminal bud instead of the two subterminal ones. Would this change the form and habit of the plant?

6. **Summary of observations.** Answer the following questions in the form of a summary on your laboratory sheets:

a. What relation exists between the position and arrangement of leaves, buds, and branches in the lilac?

b. What is meant by the body plan of the plant body?

c. What relation have the position and growth of buds to the form of the lilac shrub? Illustrate this point by means of an outline sketch.

HERBACEOUS PLANTS

Use the catnip, ragweed, aster, or similar herbaceous plants for this study.

1. **The main axis.** What is the form of the entire central axis of the plant, including both stem and root? Is this central axis mechanically adapted to the support of the lateral roots, branches, and leaves? Be able to explain to an instructor. Is the main axis of the stem the same in shape as that of the root? Is the entire axis divided into nodes and internodes? Are the internodes of the same length in all parts of the axis?

FIG. 3. Cyclic body plan and leaf display of the milkweed (*Asclepias*)

Note that the cyclic leaf arrangement secures the maximum light exposure. Photograph by Jesse L. Smith. From Bergen and Caldwell's "Introduction to Botany"

2. **Lateral members.** Are the leaves cyclic or spiral in arrangement? How many of the lateral buds have produced branches? Have these lateral branches the same plan and leaf arrangement as the main

axis? Have the lateral roots the same arrangement as the leaves and branches? Have they any definite arrangement?

3. **Bud structure, arrangement, and growth.**

a. Structure. How do the buds of an herbaceous plant, like the catnip, ragweed, or aster, differ from those of a woody plant like the lilac? Can you give reasons for the differences observed, based upon the annual and perennial habits of the two plants?

b. Arrangement and growth. Compare the buds of the herbaceous plant examined with those of the lilac as regards arrangement and mode of growth. Is the form of the plant you are examining determined by the differences in the time and rate of growth of the terminal and lateral buds? For example, why are the upper branches shorter than the lower? Why is the main axis longer than any of the branches? How explain the conical or rounded form of herbaceous plants on the basis of bud growth?

4. **Light, air, and soil relations.** What is the form of the entire plant under examination? Are the leaves, flowers, and seeds effectively displayed to sunlight and to air currents? Are the tips of the lateral absorbing roots properly placed for absorbing water and soil salts? Consult Figs. 8 and 9 of the text.

a. Construct an accurate outline drawing of the plant you are studying, indicating the following points:

(1) The form of the main central axis and the arrangement of lateral members.

(2) The plan of the lateral branches, including the position of leaves, flowers, and fruits if present.

(3) The general form of the entire plant and the display of absorbing leaf and root surfaces.

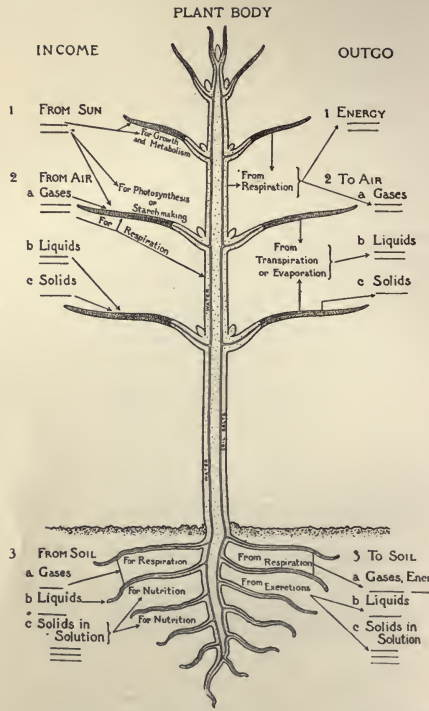

Fig. 4. Diagram illustrating the general nature of the income and outgo of a green plant from the forces and materials of its environment

The student is expected to fill in the details under the captions Energy, Gases Liquids, and Solids (consult Chapter I in the text). Do not fill in a detail unless it is correct to do so. The diagram is merely suggestive

The Relation of the Catnip, Ragweed, or Aster to the Environment

1. Read Chapter I of the text carefully. Indicate in connection with a diagram of a catnip, ragweed, or aster the income and outgo of the plant as outlined in Fig. 4 of these exercises.
2. Summarize in your notes the essential differences between the income and outgo of the plant sketched and that of a man. Consult Figs. 2 and 3 of the text and the accompanying discussion in Chapter I.

TREES

Spruces and Pines

1. **Form and general arrangement of parts.**
   a. Are the pines and spruces of the erect or of the spreading type? Compare them with oaks, maples, and similar trees. What determines the fact that the pine has a continuous excurrent trunk? What determines the uniform gradation in the length of the branches from the apex to the base of the tree? Do the branches appear to have any regular arrangement on the trunk? Recall your work on the growth of buds and branches in the lilac.
   b. Are the leaves properly disposed over the crown to secure the maximum amount of sunlight? Does the form and the angle of divergence of the upper and lower branches from the tree trunk contribute to the exposure of the leaves to light? Are the cones and seeds favorably situated for seed dispersal?
   c. Sketch the spruce or pine tree examined, in a manner similar to that outlined for the lilac and the herb.

Draw a few branches with leaves on the upper, middle, and lower portions of the trunk. Indicate the position of the remaining branches by circles or

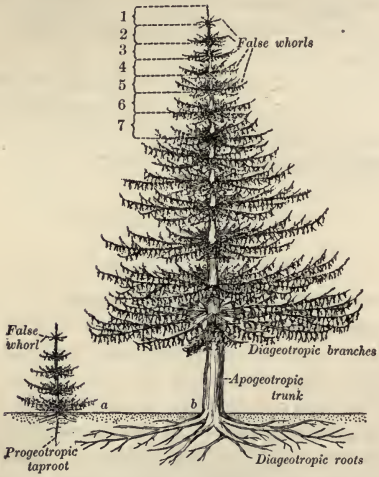

FIG. 5. Pine trees illustrating the erect type

a, a young pine ; *b*, a mature pine. Observe the excurrent trunk, the false whorls of branches, and the pyramidal form. Consult the text for the main factors concerned in the seasonal growth (1–7) and the development of these external features of the pine

other symbols. Consult Fig. 5 above and the text discussion on the form and development of the pine.

d. Summarize briefly the facts relating to bud and branch growth which determine the erect pyramidal form of the pines and spruces.

2. **The plan and development of the branches.** Select the terminal portion of a branch of a spruce or pine representing three or four years of growth in length. The spruce is best for this study, but a pine branch may be used.

a. The parts and their arrangement.

(1) Are the leaves cyclic or spiral in their arrangement? This is most easily determined on naked portions of the twigs by means of the leaf scars. What is the number and position of the buds? Is there a bud in the axil of each leaf, as in the lilac? Are the branches disposed like the buds on the main axis? Are the smaller twigs arranged like the main branches? Is the relation between leaves, buds, and branches the same as in the lilac and the herbaceous plant studied?

b. Seasonal growth of buds and branches.

(1) Determine the limits of each season's growth in length on the main axis and the lateral branches. Is there a uniform number of buds which grow each season to continue the central axis and to produce lateral branches? Are some branches more vigorous than others? Do the vigorous lateral branches produce twigs and buds disposed like those on the main central axis of the branch? Observe old branches of pine and spruce. What becomes of the lateral branches produced each season? Do the leaves persist on the main axis between the annual branches? The clusters of lateral annual branches in the pine and spruce are called *false whorls* of branches.

(2) Sketch the entire branch examined above, to illustrate the points outlined under *a* and *b*. Illustrate

the arrangement of the leaves on a small portion of a single twig. Label all parts correctly.

(3) Sketch, in outline merely, a long mature branch. Label correctly.

3. **The plan and development of the tree.**

a. Compare the arrangement of the branches and buds on a small tree with those of the branches just studied. Are the branches grouped on the tree trunk as the smaller branches and twigs are grouped on the main axis of a branch? Compare the tree with the larger branch sketched above. Did these groups of branches on the main trunk arise originally from lateral buds as on the branch studied above? Why are they called false whorls of branches, instead of true whorls? Are there smaller branches on the trunk between the false whorls of vigorous branches? Compare the spruce and the pine in this respect. How do you account for the naked portions of the trunk of the pine between the false whorls of branches? How do you account for the naked trunk below the lowermost branches?

b. Observe the spruce and the pine from a short distance. Can you determine the limits of the last season's growth at the apex of a tree? How many buds grew last season, including the terminal bud and those which produced vigorous lateral branches? Can you determine the limits of each season's growth along the tree trunk? Where are the nodes and internodes on the main central axis of the pine or the spruce?

c. Sketch the last three or four years' growth at the extreme apex of a pine or a spruce. Label the parts correctly.

d. Summarize the relation of the following factors in the development of the conical form and the false whorls in the spruce and pine:

(1) The number and position of the buds that grow each season.

(2) The spiral plan of the pine and the spruce, and its relation to the false whorls of branches.

(3) The effects of pruning. Consult the text (pp. 19 and 20) on the development of the pine.

The American Elm

Select a terminal shoot of an elm representing three or four years of growth, and observe the following points, as in the pine and spruce just studied:

1. **The plan and development of an elm branch.**

a. Leaves and buds.

(1) Compare the leaf and bud arrangement on the elm branch with that of the lilac, ragweed, and spruce. Are the leaves and buds in the elm arranged like those of any one of the plants thus far studied? Is the leaf arrangement favorable to the maximum exposure to light? Observe an entire elm branch from above. Observe the leaf petioles. Do they curve so as to bring all of the leaves in one plane? Observe the buds. Is there a true terminal bud or is it subterminal, that is, just below the apex of the shoot?

(2) Sketch a single terminal twig of the elm to illustrate the arrangement of buds and leaves and the light relation of the leaves. Label parts carefully.

b. Seasonal growth of buds and branches.

(1) Determine the age of the main axis and of the lateral branches by means of bud-scale scars.

(2) Study the annual growth of the main central axis and of the larger lateral branches. How many seasons of growth in length are represented in each?

(3) How many buds, including the subterminal and lateral buds, grew to produce the central axis and lateral branches of the last season's growth at the end of the shoot? How many buds, including the subterminal and lateral buds, grew into branches in each of the previous seasons represented on the shoot you are examining? Is there a general similarity in the number and size of the branches produced each season? Did the main axis of the branch grow equally each season? (See Fig. 6.)

c. Vigorous buds and branches. Are the larger branches produced at about the same place, and are there approximately the same number each season? Is there any similarity in the number and position of weaker branches produced annually?

(1) Study the buds laid down on the main axis and the lateral branches for next season's growth. Are some larger than others? Have these larger buds the same relative position as the stronger branches on the annual growths of previous years? As the branch grows larger, what becomes of the vigorous lateral branches and of the weaker ones of each season? Observe a large branch to determine this point.

d. Comparisons. Compare the elm branch and that of the spruce or pine already studied as regards the annual growth of buds into branches. To what do the vigorous seasonal branches of the elm correspond in the pine? Did you find anything in the pine or spruce corresponding to the weaker annual branches in the

elm? Be able to explain any difference observed in this respect. As the elm branch grows, what becomes of the stronger and the weaker branches?

e. Drawing. Remove the leaves from the branch under observation. Draw the entire branch in outline, indicating clearly the following structures:

(1) The limits of each season's growth in the length of the main axis and the lateral branches.

(2) The vigorous and the weaker branches of each season.

(3) The vigorous and the weaker buds in the terminal twig of the main axis and one or two lateral branches.

2. **The plan and development of the tree.** Study young and mature elm trees in the field, beginning observations with a young elm.

a. Young elms.

(1) Observe carefully the main trunk or central axis of a young elm and the arrangement of the branches. Compare the arrangement of the vigorous and the weaker branches of the tree with that of the branch studied above. Can you determine the limits of annual growth on the main trunk, as you can on a branch, by the vigorous lateral branches produced each season? Are the weaker branches being pruned by shading? Consult Fig. 6 and the text discussion on page 21.

(2) Do you find anything corresponding to the false whorls of branches of the pines and spruces? How does the elm differ from the latter trees in the production of false whorls of vigorous branches? Did the trunk of the elm below the present branches ever have lateral branches? If so, why is the trunk smooth now?

FIG. 6. Growth of the American elm, an illustration of the spreading type of trees

The letters from left to right show several stages in the development of the elm. The ultimate form is determined by the body plan, the method of bud growth, and the pruning effects. The corresponding letters on each figure indicate the vigorous (and so successful) branches produced each season. For further discussion consult the text

(3) Sketch a young elm to show the vigorous branches, which correspond to false whorls in the pines, the annual growths in the length of the main axis, and the weaker branches. Indicate also the scars or other markings where branches have already been naturally or artificially pruned.

b. Older elm trees.

(1) Examine older trees of the American elm with the points in view which you observed above in young elms. Is the main crown of an old elm tree formed entirely from the so-called false whorls of vigorous branches laid down in the young elm? Study the mode of growth of the main branches from base to apex. Do they repeat in their growth the history of the tree? Consult Fig. 6 (*a–f*), and Figs. 12 and 25 of the text.

c. Summary. Summarize briefly the part played by each of the following factors in the development of the elm:

(1) The spiral body plan and the differences in the buds produced each season as regards size and vigor.

(2) The unequal growth of the buds each spring and the difference in the development of the branches produced by them.

(3) The effects of natural and artificial pruning.

(4) The annual leaf display.

Consult the summary in the text (p. 23).

SUPPLEMENTARY TREE STUDIES

Some trees illustrate the above principles relating to tree development more strikingly than the elm. This is particularly true of young Norway maples and the Carolina poplar. Study the development of these and other deciduous trees with reference to the three principles deduced from the study of the pine and the elm. These principles are the *body plan* or arrangement of leaves, buds, and branches; the *unequal vigor and growth of buds and branches*; the effects of *pruning* in eliminating all but the most vigorous branches, which then occur in false whorls resembling those of the pine.

B. ADJUSTMENT TO THE ENVIRONMENT

THE EMBRYO AND SEEDLING OF THE BEAN

1. **Structure of the seed and embryo.**
   a. Remove the protective seed coat from a soaked seed of a garden bean and study the embryo. The parts of the bean embryo are similar to those of the pea (Fig. 13 of the text). Compare with *A* and *B*, Fig. 7.
   b. Find the two large food-storing leaves, or cotyledons, comprising the bulk of the embryo. Remove one cotyledon. Observe the plumule, or terminal bud of the embryo, composed of two or three delicate leaves. Find also the hypocotyl, or stem which bears both cotyledons and plumule. The first, or primary, root also grows from the end of the hypocotyl.
   c. Draw the parts of the embryo as they appear with one cotyledon removed.
2. **Adjustment of the embryo by tropisms or movements.**
   a. Emergence of the embryo from the soil. How is this accomplished? Sketch a plant which has just emerged from the soil, indicating the position assumed by the various organs. Contrast the bean with the pea and morning-glory (Fig. 7). Label correctly.
   b. Adjustment of the organs of the bean to the environment.
      (1) Study two or three stages in the development of growing seedlings of beans. Observe the changes in the position of hypocotyl, epicotyl, leaves, and roots as development proceeds.
      (2) Sketch the most mature seedling observed, and also younger seedlings, to show the positions assumed by the organs at each stage. Label all parts correctly.

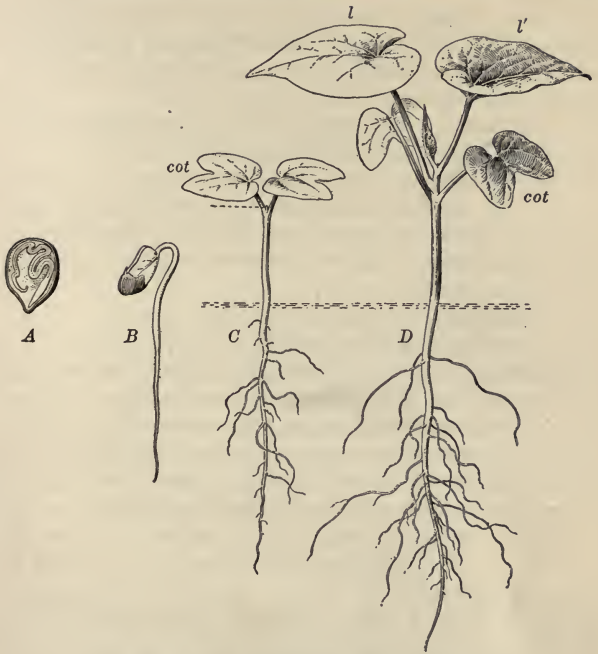

FIG. 7. Seed and seedlings of morning-glory

A, section of seed, showing the embryo surrounded by the endosperm; *B*, *C*, *D*, stages in the development and adjustment of the embryo to light and soil; *cot*, cotyledons; *pl*, plumule

c. Special motor organs, or pulvini.

(1) Observe the pulvini of the bean leaves (Figs. 15 and 16 of the text). How do they differ from the remainder of the petiole? Study the form of the *pulvinus* on leaves in different positions. Do you

observe changes in the form of the pulvini corresponding to the positions assumed by the leaves? How does the pulvinus effect the movement of the leaf blade?

(2) Draw a leaf with pulvini greatly magnified. Label all parts of your drawing.

d. Naming of stimulus and response. Label the parts of the largest seedling drawn in such a manner as to indicate the tropism and response of each organ in accordance with the nomenclature given on page 30 in the text.

3. **Experiments.** Observe the following experiments on the tropisms of the bean seedling:

a. Place one growing seedling of a bean in a horizontal position, and another in an erect position, in a place where the lighting will be uniform on all sides. Observe at successive laboratory periods until both plants are adjusted in their positions. Write up the experiment after the following plan, indicating actual results by drawings properly labeled to indicate the kinds of stimuli and the nature of the response in each instance.

(1) *Object in view in performing the experiment.* What do you expect to prove?

(2) *The method and conditions under which the experiment is performed.* Make outline drawings of the two plants to indicate the position of leaves and stems at the beginning of the experiment.

(3) *Actual results observed on each plant after several hours.* State the changes observed in each plant. Indicate these changes by outline drawings. Explain the mechanism of the response in the case of each organ. Label each organ, indicating the

nature of the stimulus and response; for example, apogeotropic. Consult the text discussion (pp. 28–31) concerning the mechanism of response in plants and the naming of stimulus and response.

(4) *Conclusions.* State briefly your conclusions from the above experiment as to the relations existing between the bean plant and some of the forces of the environment.

b. Place two plants before a window. Rotate one on a clinostat. Observe and record as indicated above after several hours, when the plants have become adjusted to the new environmental conditions.

c. The gravity sense. Observe germinating seeds of corn or beans with protruding roots which are rotated on a clinostat, as in Fig. 18, *a–d*, of the text. Compare the position assumed by the rotated roots and hypocotyls with positions taken by these organs in seeds pinned to a stationary disk. Record the object, method, results, and conclusions as in experiment *a*, above.

SUPPLEMENTARY STUDIES

Adjustments of common plants to the environment. Observe common plants in the field and in the laboratory, and record the positions assumed by the various organs. Record the results of your observations and your conclusions in a manner similar to that indicated above for writing up experiments on movements. The dandelion (*Taraxacum*), white sweet clover (*Melilotus*), cultivated geranium, and some climber, such as the ivy, are good species for observation. At least one such plant should be assigned to each student to work up independently and hand in with appropriate drawings and notes.

SECTION II. CELL STRUCTURE AND GROWTH

A. THE CELLULAR STRUCTURE OF PLANTS

1. **Mounting sections.** Mount sections of cork, pith, or similar materials as follows for microscopic observation: Clean a slide and cover glass as directed by an instructor. With the point of your scalpel or with a small brush place a section of pith or cork in the center of a glass slide. Add a drop of alcohol with a pipette. Take a clean cover glass with forceps, or grasp it by its edges between thumb and forefinger. Place one edge of the cover glass on the slide at the edge of the drop of alcohol and gently lower the cover glass over a specimen. This method of placing a cover glass over an object avoids air bubbles, which appear under a cover glass as dark rings with light centers. Now observe your section with the compound microscope as indicated below.
2. **Low-power study.** Place the section, mounted as directed above, on the stage of the microscope for observation. Adjust your mirror until you have a white field, and make the following observations and drawings:
   a. Compare the appearance of your section with that of a similar section of a honeycomb. Is it made up of cells, like a honeycomb, with similar bounding walls and cavities? Compare your section with a piece of honeycomb if the latter is available.
   b. Make an accurate drawing of a portion of your section as it appears under a low power. Label the parts with appropriate terms corresponding to similar structures in a honeycomb.

c. Who made the first observations similar to the one you have just made? What conclusions did he draw concerning the structure of plants? Consult the text (Chapter IV, p. 54).

3. **High-power study.** Observe a portion of the above section under high power, being careful to secure good light.

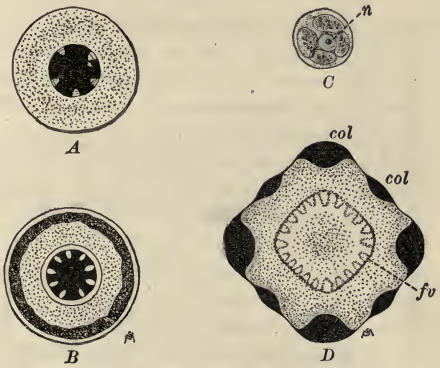

FIG. 8. Cell and tissue differentiation in plant organs
A, cross section of a root with dark pith, light vascular bundles, and dotted cortex; *B*, cross section of flower stalk with tissues as in *A* but with an outer layer (dark) of thick-walled strengthening collenchyma cells; *C*, single-celled alga with nucleus (*n*); *D*, cross section of a square-stemmed plant (*col*, collenchyma, as in *B*; *fv*, fibrovascular bundles; pith and cortex dotted)

a. Cell walls. Note their thickness, color, and connections in adjacent cells. Is the cell wall split at the junction of adjacent cells to leave minute spaces, called intercellular spaces?

b. Cell cavities. Note their size, shape, and contents. Are the cell cavities of adjacent cells similar in these respects? Do the cavities of these cells contain anything besides air?

c. Draw two or three cells greatly magnified (half an inch in diameter), to illustrate the parts of plant cells as seen under a high power. Label all of the parts of one cell carefully.

CELL-WALL THICKENING AND CELL DIFFERENTIATION

1. **Sections of celery, corn, or a similar plant.**

a. Cell differentiation. Observe the entire section with the low power of a compound microscope. Are the cells in different parts of the section of uniform size and form? Why should one expect to find different kinds of cells in the cell colony which makes up the structure of any stem, leaf, or root? Observe any definite order or grouping of similar kinds of cells. Explain such groupings on the basis of use, or function, in a celery or corn stalk. The regular oval cell masses are *vascular bundles*, which conduct water and foods up and down the stem.

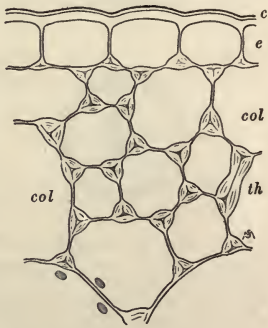

FIG. 9. Epidermis and collenchyma

ep, epidermis; *col* (collenchyma), the thick-walled cortex cells; *th*, thick-walled portion of collenchyma cell

b. Make an outline sketch of the entire section as it appears to the naked eye or with a hand lens. Shade in the areas showing thick-walled cells, and outline the vascular bundles. Consult Fig. 7. Label.

c. Cell-wall thickening. Focus with a high power on some thick-walled cells in the section. Observe the thickness of the cell wall and the size of the cell cavity. Are there intercellular spaces as in the thin-walled pith cells? Consult the text concerning the mode of cell-wall thickening (p. 48).

d. Draw three or four thick-walled cells.

2. **Vegetable fibers in paper.**

a. Examine pieces of filter paper and newspaper under the low power of a compound microscope. What appears to be the composition of the paper? Make a rough sketch to indicate the structure as it appears under low power.

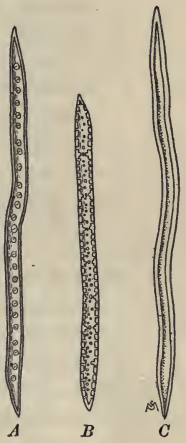

FIG. 10. Thick-walled fibrous cells

A, tracheid from pine wood; *B* and *C*, fibrous cells

b. Tease out a small piece of each kind of paper with needles in a drop of water and mount separately on the middle of a glass slide. Cover with a cover glass and study with both low and high powers of the compound microscope. What is the shape of these vegetable fibers? Have they a cell wall and a cell cavity? Compare them with the thick-walled cells observed in celery.

c. Draw two or three fibers accurately from each specimen examined and label their parts. Consult Fig. 10 of these exercises. The fibers of which paper is made resemble *C* in structure and in shape.

d. What is the function of thick-walled cells and fibers in plants? What function do they serve in the celery stalk examined above? Why is a cornstalk hard on the outside? What makes a bamboo fishing rod so strong? What is the nature of the covering of hickory nuts and other similar nuts? See Figs. 8, 9 and 10 of these exercises.

e. Summarize the functions of thick-walled cells and vegetable fibers in plants, and state some of their important economic uses.

PROTOPLASM, VACUOLES, AND NUCLEI IN ROOT-TIP CELLS

1. **Study of the text and sections.** Read the text concerning the nature of protoplasm, vacuoles, and nuclei. Study these parts of the cell in sections of root tips which have been previously stained and mounted for this purpose. Transverse sections of root tips are especially favorable for this first study of cells with protoplasmic contents.

   a. Low-power study. Study the cells immediately beneath the outer bounding cell layer.

   (1) *Protoplasm and vacuoles.* Find cells in different stages of vacuole formation as described in the text and illustrated in Fig. 27. Do you find cells in which vacuoles are just beginning to form? cells in which the vacuoles are large light spaces surrounding the nucleus? cells which appear to have a continuous large central vacuole? These may be found in deeper-lying cells of the section.

   b. High-power study. Select a favorable cell and study the following structures with a high power:

(1) *The nucleus.* What is the general nature of the nuclear protoplasm? Does it appear granular or homogeneous? Compare the nuclear protoplasm with the regular cell protoplasm or cytoplasm. Can you detect a thin nuclear membrane, or wall, around the nucleus, and a darker granule, the nucleolus, within the nuclear cavity? Is the nucleus located in the center of the cell? How is it supported in this position?

(2) *Vacuoles.* What forms the bounding walls of the vacuoles? What are they supposed to contain in living cells? What is the origin of vacuoles and how do they grow? Consult the text.

(3) *The cytoplasmic sac.* What is the cytoplasmic sac and how formed? What relation does the cytoplasmic sac bear to the general protoplasm of the cell? to the central vacuoles and to the cell wall?

(4) Draw two cells greatly magnified (one inch in diameter) to illustrate two stages in the formation of vacuoles. Put details of the nucleus and cytoplasm in each cell.

CELL STRUCTURE AND PROTOPLASMIC STREAMING IN STAMEN HAIRS OF *TRADESCANTIA* (SPIDERWORT)

1. Mount some of the delicate, hairlike outgrowths (stamen hairs) which grow out from the stamens in flowers of *Tradescantia*, the common spiderwort. Preserved material may be used for the cellular structure of the stamen hair.
2. **Low-power study.** What is the general cellular structure of a stamen hair? How do the cells composing it differ in size and form at the smaller apex and at the larger

basal portion of the hair? How are the cells joined at the ends? Have they cell contents? See root-tip cells.

a. Draw a figure illustrating the form and appearance of the cells of a stamen hair as seen under low power. Label all parts observed.

3. **High-power study.** Select large cells near the base of a stamen hair in which the internal structures are plainly visible.

a. Compare the structure of such stamen-hair cells with that of root-tip cells as regards the following points:

(1) *Cell shape and outline.* How do stamen-hair and root-tip cells differ in form and outline? Can you think of a reason for the differences you see? What is the geometrical form of a stamen-hair cell at the larger basal end of the hair? at the smaller apical end?

(2) *Cell wall.* Is the cell wall smooth or roughened? thick or thin? colored or colorless?

(3) *Cell contents.*

(*a*) *The nuclei.* Where are the nuclei located in different stamen-hair cells? Have they the same position in all cells of a single hair? Can you determine by focusing whether the nucleus is in the center of the cell or next to the cell wall? Try this experiment in different cells. Result? Be able to explain to an instructor.

(*b*) *The cytoplasm.* Do you find cytoplasm around the nucleus? How is it disposed in other parts of the cell? Is it denser in some areas than in others? What is the character of the cytoplasm as seen under high power? What parts of it are visible? What do you conceive

to be the structure of the cytoplasm in these stamen hairs? Compare with root-tip cells.

(*c*) *The vacuoles.* How many vacuoles are there in the stamen-hair cells? Are the cells all alike in this respect? Is there a cytoplasmic sac in all stamen-hair cells? What relation does the nucleus sustain to the vacuole and to the cytoplasm?

(4) Draw the following diagrams of a stamen-hair cell to illustrate its form and structure: Draw the cell as it appears when the nucleus is in focus. What kind of view of the cell is this? Express this view by an appropriate term. Construct a transverse section of a cell as it would appear if cut through the nucleus.

4. **Living stamen hairs and protoplasmic streaming.** Mount living hairs of *Tradescantia* in water and observe with low and high powers for protoplasmic movement.

a. Low-power observations. To what is the color of the stamen-hair cells due? Can you detect the nucleus and the protoplasmic strands? Select a good cell for observation, and focus upon it carefully with high power.

b. High-power study of living protoplasm and its movements. What seems to be the nature of the living protoplasm of a stamen-hair cell? How would you describe it? Does the protoplasm exhibit movements? Is there one general movement of the protoplasm or are there several streams? Is the movement definitely related to the nucleus?

c. Draw a stamen-hair cell showing the position of the nucleus and cytoplasmic strands. Indicate by arrows the direction of movement of the protoplasm.

PLASTIDS IN PLANT CELLS

Chloroplastids in Cells of *Elodea canadensis* (Water Weed)

1. Mount in water young leaves of *Elodea* selected from the apex of *Elodea* plants, and observe as follows:
   a. Cellular structure of the Elodea leaf.
   (1) What is the nature of the cells which compose the *Elodea* leaf? Are they uniform in size and shape? What is the color of the cell walls? What is the nature of the cell contents?
   (2) Draw an outline diagram of the *Elodea* leaf. Indicate, by lines or by shading, the main cell areas of the leaf. Fill in three or four cells of each area to show the cell structure of the leaf.
   b. Chloroplastids. Observe the form and appearance of the green grains, or plastids, in the *Elodea*-leaf cells. Do these plastids occupy the same position in all the cells? Is there any regular or uniform position assumed by the plastids?
   c. Protoplasmic streaming. This is usually best observed in the elongated cells composing a central strand, or midrib, in each leaf.
   (1) Observe this streaming movement. Is there one direction for the movement of protoplasm in different cells in *Elodea*? Does the protoplasm stream from cell to cell through the cell wall? Do these cells have a cytoplasmic sac?
   (2) Draw two or three cells of *Elodea* accurately, indicating the form and position of the plastids. Indicate directions of movement by means of arrows. Draw two or three plastids greatly magnified.

d. Composition of chloroplastids. Select shoots of *Elodea* which have been previously boiled to kill the plastids. Place one or more shoots in a test tube in ninety-five per cent alcohol and observe frequently. Does the alcohol change color? Why? Allow these test tubes to stand until the next exercise. Examine the alcohol, the plants, and the plastids. Do the plants appear to be somewhat bleached? Explain. What are the parts of a chloroplastid? Answer the above questions in your notes, indicating the form, parts, and function of chloroplastids in cells of *Elodea.*

Chromoplastids

1. Examine chromoplastids in the cells of flowers (for example, *Nasturtium*) and fruits (for example, tomato and bittersweet berries). Draw the chromoplastids examined.
2. See the text discussion of the structure and functions of plastids.

B. CELL STRUCTURE AND GROWTH

GROWTH

1. **Growth of root tips in living roots of corn or beans.**
   a. Observe growing root tips which have been previously marked with uniform millimeter spacings and then allowed to grow for twenty-four hours or more. In what part of the root tip has growth taken place? How long is the growing zone as indicated by the millimeter spaces? Does the root grow at the very tip?
   b. Draw a root which has grown in the manner indicated above. Indicate the length of the millimeter spaces

accurately. Locate the rootcap if possible. Consult the text on the parts of the root tip and label your figure correctly.

2. **Cellular structure and cell growth of root tips.** Select prepared slides cut lengthwise through growing root tips and study the cellular structure of the main root-tip areas.

a. Note the division of the root into an outer epidermal cell layer, a central axis cylinder, and an intermediate cortex, each composed of similar cell elements. Consult the text figures and Fig. 11 on the structure of the root tip.

b. Rootcap. What is the character of the cells of the rootcap? Do its cells differ at the extreme apex of the root and at its upper border? What is the geometrical form of the rootcap? How is it related to the growing meristem cells and the growing cell zones above it? What is the function of the rootcap? How is it renewed when worn off by the soil?

c. Meristem layer. What is the form and extent of the meristem cell layer? What are the distinctive characteristics of its cells as regards size, form, and cell contents? Is the meristem a distinct layer of cells or do its cells merge into the cells of the rootcap below it and into those of the elongating zone above it?

d. Elongating zone. Study the cells at the lower and upper margins of the elongating zone. How do they differ in these two regions from the cells in the central region of the elongating zone? Explain the changes which you note in the cells of the elongating zone from its lower to its upper margin. How are these changes in the cells brought about? How is the

elongating zone renewed when its cells become converted into cells of the maturing and permanent zones of the root above it? Consult the text.

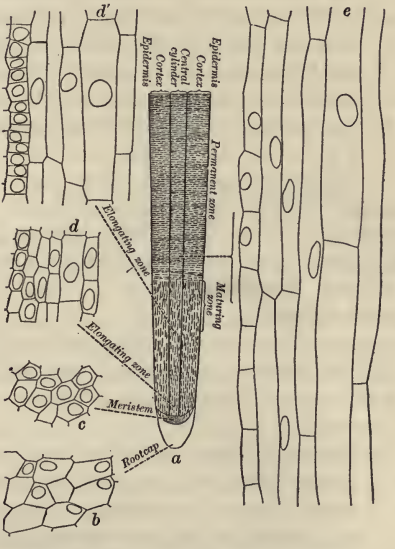

FIG. 11. The growth of cells in a root tip

a, main areas of the root tip, shaded; *b–e*, camera drawings of cells from the various regions of the root as indicated in the figure. Note the changes in form and size of the cells as growth proceeds. The nuclei grow with the cells, but they occupy a proportionately smaller part of the cell cavity as the cells enlarge

e. Permanent zone. How do the cells above the elongating zone differ from the cells below them in form and in cell contents? Explain the changes which have taken place in these cells with their growth.

f. Drawings of cells characteristic of each root zone.

(1) Select a small group of about three cells from each zone of the root, and outline each cell group on the same scale as that shown in Fig. 11.

(2) Fill in the details of cytoplasmic and nuclear structure in a group of cells of the rootcap, meristem, and elongating and permanent zones. Indicate clearly the growth of vacuoles and the origin of the cytoplasmic sac incident to growth. See Fig. 11 for the proportionate size and form of cells in the main zones of the root.

3. **Elongation.** Read the discussion in the text on the method of elongation of the root by cell division and growth. Summarize the facts relating to the cellular growth of the root in length.

4. **Structure and growth of buds.**

a. Structure of buds. Review the parts of the bud of the lilac as seen from the exterior. Cut median vertical long sections of buds and study the cut surface with a hand lens.

(1) Determine the parts of the bud and their relation to each other. Is there an apical meristem as in roots? Observe the relation of leaves to nodes and internodes. If prepared slides are available, observe the cellular structure of the above portions of a bud. Make an accurate drawing of a long section of a bud and compare it with that of roots. See Figs. 37 and 40 of the text.

b. Growth of buds. Observe buds which are expanding in growth. (Preserved material may be used if fresh is not available.) What is the general method of elongation? Is the elongating zone in buds a continuous product of the meristem, as in the root? Is

the elongating zone in the bud derived from a meristem, as in roots? Be able to explain the similarities and differences between roots and stems in these respects.

c. Summarize in your notes the similarities and differences between root growth and stem growth by means of buds. Distinguish between the growth of woody and herbaceous stems. Consult the text summary (pp. 69–72) on the growth of roots and stems.

C. THE CELL AND CELL DIVISION

1. **Minute structure of the cell.**
   a. Select a well-stained cell in the cortical region just above the meristem and study it carefully with the highest-power ocular and objective available. Read the text description of such a cell.
   b. Do you see any indication of the mesh structure of cytoplasm mentioned in the text? What is the structure of the chromatin? Can you find the nuclear vacuole surrounding the nucleolus?
   c. Draw the cell you are observing, greatly magnified, to show the structure of the cytoplasm and the nucleoplasm (chromatin) as they appear in your section.
   d. Observe the chromatin in other nuclei of the root tip. Do you see any of the variations in its structure noted in the text?
2. **Cell division (mitosis).**
   a. Prophase. Select a nucleus in a root-tip cell which shows the condensed condition of chromatin in the form of chromosomes.
      (1) *Chromosomes.* Is the nuclear membrane still present in a nucleus with chromosomes? What is

the shape and color of the chromosomes? Are they all of the same form and color? Have they any definite position in the nucleus with reference to the nuclear membrane?

(2) *Spindle.* Do you see any evidence of a forming spindle at the two ends, or poles, of the nucleus you are studying? See the text on the origin and structure of the spindle.

(3) *Cytoplasm.* Is the cytoplasm of the same structure around the nuclear membrane and at the periphery of the cell? If any difference is noted, in what does the difference apparently consist? What is the apparent structure of the cytoplasm?

(4) Draw a cell greatly magnified (1 or 2 inches in length) to bring out the above points. Draw the chromosomes very accurately.

b. Metaphase.

(1) *The nucleus and the nuclear membrane.* Do you find any definite nuclear membrane and nuclear cavity in the metaphase stage? What changes have taken place in the nuclear membrane since prophase?

(2) *The chromosomes.* Has their form changed since prophase? Have the chromosomes a definite arrangement in metaphase? How are they apparently supported in their position? If you could see a polar view of the chromosomes in metaphase, what arrangement would they appear to have? Indicate this position of the chromosomes in an outline drawing.

(3) *The spindle.* Observe the spindle carefully with a high power. What is its apparent structure? its form? Can you determine any definite relation

of the spindle fibers to the chromosomes? What relation does the spindle sustain to the surrounding cytoplasm?

(4) Draw a metaphase stage. Outline the entire cell. Draw in the spindle, the chromosomes, and the cytoplasm in one half of the cell. Label accurately.

c. Anaphase.

(1) *The chromosomes.* Note the form and position of the chromosomes in anaphase. How have the two sets of daughter chromosomes, seen in anaphase, been derived from the single set observed in metaphase? Have the daughter chromosomes the same form as the mother chromosomes of metaphase? Are they as large as the mother chromosomes?

(2) *The first spindle.* Are there spindle fibers between the two sets of daughter chromosomes? If so, do they have the same appearance as they have in the polar portions of the spindle? What is meant by traction and supporting fibers of a spindle? Do you see any such distinction in the fibers of the anaphase spindle?

(3) Draw the spindle and chromosomes in an anaphase stage. Label all parts accurately. Indicate the position of traction and supporting fibers.

d. Telophase.

(1) *Early telophase.* Observe, if possible, an early telophase stage in which the chromosomes are aggregated at the poles, as described in the text.

(*a*) *Chromosomes.* Have the chromosomes changed their form since the anaphase stage? What relation do they sustain to each other? Are they separated or joined?

51167

(*b*) *Spindles.* Are the spindle fibers still present in early telophase? Do they form a spindle? Are these fibers a part of the original spindle seen in metaphase? If so, to what part of the metaphase spindle do they correspond? Do you observe any evidence of traction fibers in telophase?

(*c*) Draw an early telophase stage. Label all structures accurately.

(2) *Late telophase.* Select cells in which the daughter nuclei have begun to form, preparatory to cell division.

(*a*) *Daughter nuclei.* What is their structure? Have they a definite nuclear membrane? What is the structure of the chromatin in the daughter nuclei? Is there any evidence of the chromosomes which were seen in early telophase?

(*b*) *The second spindle.* The spindle between the daughter nuclei is here termed the second spindle, to distinguish it from the first spindle, which was concerned with the division of the nucleus in metaphase and anaphase. What is the form of the spindle which connects the daughter nuclei? Are the fibers evident in all parts of the spindle? Are they denser in one part than in another? Observe dividing cells in which the equator of the spindle extends completely across the cell.

(*c*) *The cell plate.* Do you find the cell plate extending across the equator of the spindle? Does it stain like protoplasm? What is its supposed composition? Does the plate extend completely across the cell in your specimen?

If not, find a cell in which this is the case. Note the relation of the cell plate to the spindle.

(*d*) *The cell cytoplasm.* What is its relation to this second spindle? Is the cytoplasm reforming between the daughter nuclei?

(*e*) Draw a stage in cell division, indicating the structure of the daughter nuclei, the spindle, and the cell plate. Draw the cytoplasm in one half of the cell. Make one drawing of the spindle and cell plate in which the cell plate extends completely across the cell.

SUPPLEMENTARY STUDIES IN MITOSIS

1. **Prophase.** Search for nuclei which illustrate the condensation of chromatin from the resting stage into the chromosome condition. See the text on the following changes in the chromatin during prophase.

   a. Irregular dense masses of chromatin. Observe and draw one or more nuclei in which the chromatin has condensed into irregular dense masses. Is there any definite arrangement of these chromatin masses?

   b. Regular spiral arrangement. Observe nuclei in which the chromatin appears in a regular spiral thread in the nucleus. This is usually termed the *spireme stage.* Does the chromatin appear to form a continuous ribbon or is it segmented into rods or chromosomes? What changes transform this ribbonlike arrangement of chromatin into definite chromosomes? Is there any evidence of a spindle's being formed at the poles of the nucleus you are examining?

   c. Draw the nucleus with the chromatin. Indicate the beginning spindle and surrounding cytoplasm, if the spindle is forming.

2. **Daughter nuclei.** Observe, if possible, one or more stages in the transformation of daughter nuclei into resting nuclei. See the text discussion concerning the nature of these changes. Draw the stages of daughter nuclei which you find, indicating carefully the chromatin changes.
3. **Daughter cells.** Do you find young daughter cells with reformed cytoplasm and nuclei? How was the cytoplasm reformed between the daughter nuclei? Note the chromatin and the nucleoli of the daughter nuclei. Draw.

SECTION III. ANATOMY

A. ANATOMY OF STEMS

EXTERNAL FEATURES OF WOODY STEMS

Review the following important external features of shoots of some common tree like the ash or hickory. See your previous work on the shoot and buds of lilac and elm.

1. **Buds and their relation to growth.**
   a. How many kinds of buds, as regards position, are there on the shoot you are studying? Which buds are definitely related to nodes? Are the different kinds of buds of the same size? How many buds of previous years grew into the main shoot or into lateral branches? Are the other buds still alive? Would they ever have grown into branches?
   b. Age of shoots. Can you determine how many years of growth are represented in the shoot you are studying? How are the yearly segments of growth marked off? What is the cause of these markings?
2. **The bark and its markings.** Is the bark uniform in color and appearance in the older and younger portions of the shoot, representing different years of growth? Peel off or scrape off the outermost thin brown skin with a scalpel; what is the color of the tissue beneath it? Now scrape down to the wood; do you find any new tissue layers comprising the bark of the twig?
3. **Scars and markings on the bark.**
   a. What large scars and markings do you find on the bark of the entire twig? What is the nature and position

of these scars and markings and what caused them? Observe the bark carefully with a hand lens; do you find any minute markings? Have they a definite form and distribution?

b. Drawings. Draw a portion of the shoot you are examining, representing three years of growth in length. Indicate clearly the appearance and position of the buds, the scars marking annual growth in length, leaf scars, leaf-bundle scars, and lenticels. For the meaning of these terms consult the text.

GROSS STRUCTURE OF MATURE STEMS

Study wood blocks (preferably oak) cut in cross and in long section from branches of trees. To give the best results these blocks should be smooth and polished. Observe with naked eye and hand lens. Consult the text for a general discussion of the structures observed below.

Transverse Sections

1. **Bark.** Compare the bark of a mature branch in sectional view and on its surface with that of the twigs observed above. Is the epidermis still present? the green bark? Compare the bark of a branch of the elm with that of some other tree in wood blocks. What kinds of tissue are most prominent in the bark on the branches and trunks of trees?
2. **The cambium.** Locate the position of the cambium layer, represented by a line just outside of the wood.
3. **The wood cylinder.**
   a. How many annual growth rings are represented in the block you are examining? How is the boundary line between the summer and spring wood of successive

years marked? What is the relative width and texture of spring and summer wood?

b. Observe the number and extent of the wood rays; do they all extend to the pith? What is their outer terminus?

c. The pith. Observe its size and shape.

d. Do some of your blocks show central heartwood and outer sapwood? Compare two or three different kinds of woods as regards the above points, if specimens are available.

Longitudinal Sections

1. Compare longitudinal sections of branches, cut in both radial and tangential planes, with the above transverse sections. For this purpose it is preferable to use oak blocks which present for comparison transverse, longitudinal radial, and longitudinal tangential cut surfaces.

a. Compare as follows the different surfaces of wood blocks prepared as indicated above:

(1) Determine the transverse, radial, and tangential surfaces of a wood block. Locate corresponding structures in each; namely, wood rays, annual rings of growth, spring and summer wood, and heartwood and sapwood if present.

(2) What are the distinctive features of radial and tangential cuts which enable you to distinguish them? In a tangential section, is a wood ray cut across its long axis or parallel with it? In a radial section? What is the actual form of a wood ray in a tree trunk?

(3) *Drawings.* Make accurate sketches of the three surfaces of a wood block to show the wood rays,

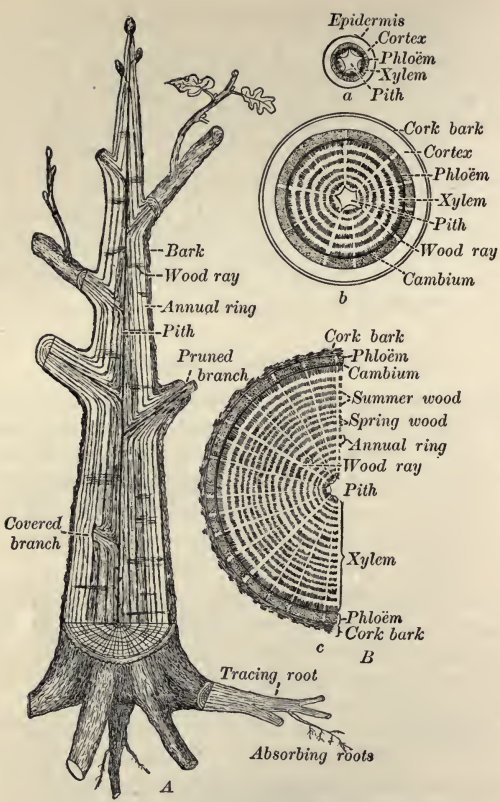

FIG. 12. The structure and growth of a tree

A, diagram illustrating the gross anatomy of an oak tree in long section. Note the relation of the annual rings, the junction of the branches with the main trunk, and the covering of pruned branches; *B*, transverse sections of the tree shown in *A*, at three levels. The figures in *B* are designed to illustrate the early, or primary, structure (*a*) and the secondary changes (*b*, *c*).

annual rings, and spring and summer wood as they appear in transverse, longitudinal, radial, and tangential sections. Indicate ducts by circles, summer wood by shading. Label these structures in each view of the block drawn.

PRACTICAL EXERCISE

Study the various cuts of finished woods represented in the finished woods in the tables, doors, and other wood furnishings in the laboratory. See Figs. 48 and 50 of the text and the discussions concerning the structure of finished woods.

1. Determine the different cuts of wood, namely, the radial, tangential, and transverse cuts, represented in the finished woods of the laboratory.
2. Determine annual rings, heartwood and sapwood, "grain," "silver grain," etc. in each of the above cuts.
3. Make sketches of the above structures in transverse, radial, and tangential sections of different kinds of finished woods. Label all structures indicated in your drawings.

MICROSCOPIC STRUCTURE OF WOODY STEMS

Transverse Sections

Observe transverse sections of shoots which are more than one year old. Use only hand lens and low power in your first studies. In preparations which have been stained with a red dye (safranine) the wood and the thick-walled skeletal tissues are stained red. The remaining tissues are usually stained purple or blue with logwood dye (hæmatoxylin).

1. **General tissue layers in sections of living shoots.**
   a. The bark. Note the limits of the layers designated as brown bark and green bark in sections of fresh twigs. Can you distinguish the epidermis and the brown

cork layer? How many tissue layers of different appearance are there between the outer cork layer and the outer limits of the wood? Observe the cells of these different layers with a low power and note the general character of each. Consult the text and

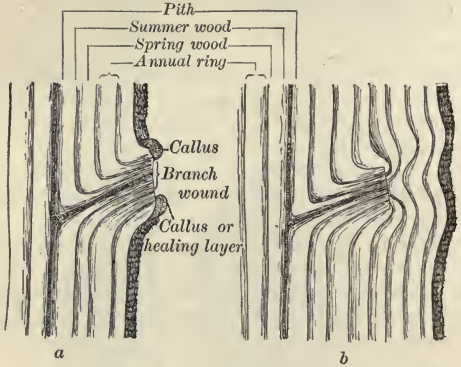

FIG. 13. Healing of a wound due to the severance of a branch

The healing is done by new tissue, called callus, formed over the wound. Observe the irregularity of the annual rings around the wound. Redrawn from Curtis's "Nature and Development of Plants"

Fig. 46 for a discussion of these tissue layers belonging to the bark. See also Fig. 52 of the text.

b. The wood. Note the following main tissues and structures of the wood:

(1) Note the number and relative cell width of the annual rings of growth; the distinction between spring and fall wood; the wood rays. The relative length and termination of the wood rays can now be accurately traced. Do they extend through the phloëm?

(2) *The pith.* Note the irregularly lobed pith in some kinds of wood. The irregularity of the pith is due to the effect of branches and leaves on the form of the pith.

c. Draw a sector of the section, indicating by shading and by circles the different layers of the bark and wood. The sector should be three or four inches from epidermis to pith and two inches wide. Draw each tissue layer accurately as regards its relative width and extent, but do not draw cells. The spring ducts may be indicated by circles and the summer wood by shading.

2. **Cellular structure of the tissues.** (Use prepared slides.)

a. The cork (*brown bark*). Study the character of the cork cells and compare them with the cork cells studied earlier in the course. Is the epidermis still present or has it been sloughed off after the formation of cork?

b. The cortex. Note its limits and the nature of its cells. Do its cells contain protoplasm and chloroplasts? Are there intercellular spaces?

c. The phloëm. See Fig. 52 of the text.

(1) *Outer phloëm layer.* Study carefully the cell walls and the contents of the strengthening, or skeletal, layer of the phloëm (stained red with safranine). Can you find cells with canal-like perforations of the greatly thickened cell walls of these cells?

(2) *Inner phloëm layer.* Note the nature of its cells and their gradual merging into the cambium (see next topic).

(3) *Cambium.* The cambium is composed of three or four cell layers adjoining the red stained wood on its inner side and the phloëm on its outer

border. Determine accurately the structure of these cambium cells. Note the orderly arrangement of the tissues of the xylem and phloëm which arise from the cambium. Why is this so? Do the wood rays arise similarly from the cambium? Are the rays continuous from the time of their origin to old age in a tree? Be able to explain this point.

d. The wood. Study carefully the following cells and tissues of the wood:

(1) *Water ducts.* Their size, contents, and cell-wall thickenings. Why are they so much larger than the surrounding cells?

(2) *Wood fibers.* Are they thick-walled or thin-walled? Have they cell contents? What is their function in a living tree trunk? Are they structurally adapted to their function?

(3) *Annual rings.* Study the relation of ducts and fibers at the junction of two annual rings. Is the boundary line between spring and summer wood a sharp one? Why is the annual ring so plainly visible in stumps or sawn logs?

(4) *Wood rays.* Observe their cell structure carefully and compare it with that of the surrounding dead ducts and fibers of the wood. Do you find pores in the end walls of these cells and protoplasmic continuity through these pores? This can be seen only in very thin and well-stained preparations. What is the function of wood rays?

(5) *Wood parenchyma.* Observe the amount and distribution of living cells with darkly stained contents in the wood outside of the rays. Are these cells in isolated or in connected masses? Are

they connected with the wood rays? with the ducts? Do they have cytoplasmic and nuclear contents? What is the function of these cells?

(6) *Drawings.*

(*a*) Draw a small portion of the summer and spring wood at the junction of the two in an annual ring. Show the details of ducts and fibers.

(*b*) Draw the cambium and a portion of the phloëm and xylem on either side of it, including at least two wood rays. Indicate the orderly arrangement of the tissues which arise from the cambium. Draw the cells and tissues with great accuracy.

Longitudinal Sections

Study thin longitudinal sections of the wood of oak, birch, or a similar woody stem. See Fig. 53 of the text.

1. Select a portion of your section in which you can demonstrate most clearly the following main wood tissues in long section: namely, ducts, fibers, living cells, and wood rays.
2. Study and draw accurately the above tissues of the wood in long section. Indicate in each tissue the relative thickness and cell-wall markings, the nature of the cell contents if present, and the shape of the cells composing the tissue.
3. Observe the form and structure of the cambium cells and the phloëm cells, consulting the text figure. These tissues are usually too difficult for accurate delineation by beginning students.

HERBACEOUS STEMS

Dicotyledons

Study the main layers of herbaceous stems in transverse section, contrasting them with similar layers of the woody stems studied above.

1. **Epidermis.** Is the epidermis present? What is the color of herbaceous stems? Are they smooth or rough? Compare the external features of woody and herbaceous stems.
2. **Bark.** What are the layers of the bark (using the term *bark* to include all tissues from the epidermis to the cambium)? Contrast these tissue layers with those of woody stems just studied. What is the function of green bark?
3. **The wood cylinder.** How does it differ from that found in woody stems? Is it an unbroken cylinder? Is it as thick as that of woody stems? Are there annual rings? How do you explain your findings on this point? Stain your section with iodine and observe again the tissues of the wood cylinder. Note the following:
   a. Dead tissues and cells. Do these appear to be similar to those of a woody-stemmed plant? If they are different, be prepared to explain how and why. Why can an herbaceous plant get along with a smaller amount of wood tissue than a tree or a shrub?
   b. Living tissues of the wood. How are these distributed in herbaceous stems? Compare with the distribution of similar tissues in woody stems. Compare the amount of living storage tissues in herbaceous and woody stems.
   c. Pith. Note the relative size of the pith in herbaceous as compared with woody stems. Is there a

difference between the two stem types in this respect ?

4. **Drawing.** Draw a sector of an herbaceous stem in outline, to show the real position and relative width of the main tissue layers of the bark, the wood, and the pith. Label each of these layers, using terms corresponding to those previously used in the study of woody stems. Point out the main contrasting points between woody stems and herbaceous stems. Consult the summary in the text (p. 108).

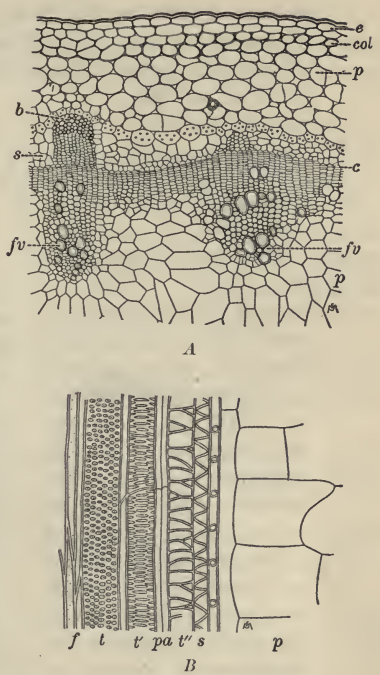

FIG. 14. Transverse (*A*) and longitudinal (*B*) sections of the stem of the sunflower (*Helianthus annuus*)

A: *e*, epidermis; *col*, collenchyma of the cortex; *p*, parenchyma of the cortex; *b*, fibrous phloëm; *s*, sieve portion of phloëm; *c*, cambium; *fv*, ducts of the xylem portion of the fibrovascular bundles. *B*: *f*, fibers of the xylem; *t*, dotted duct; *t*′, scalariform duct; *pa*, wood parenchyma; *t*″, reticulated ducts; *s*, spiral ducts; *p*, thin-walled cells of the pith. After Müller

5. **Summary of herbaceous stem structure.** Summarize the distinctive characteristics of herbaceous as compared with woody stems, in terms of bark, cortex, vascular cylinder, and pith.

Monocotyledons

Study transverse sections of stems of monocotyledons. Contrast their structure with that of herbaceous dicotyledons.

1. Is there a distinct bark in the stem of the monocotyledon that you are examining? a distinct wood ring and pith? Do you find xylem and water ducts? Is there phloëm connected with the xylem? What form is assumed by the masses of xylem and phloëm, and how are these masses (vascular bundles) distributed in the stem? Where is the strengthening skeletal tissue in a monocotyledonous stem? the storage tissue?

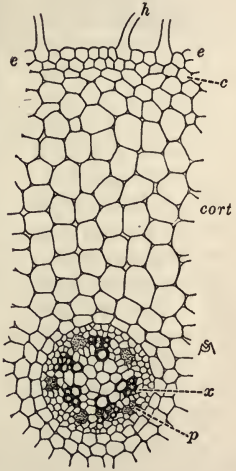

Fig. 15. Structure of a root in transverse section

e, epidermis; *c*, outer layer of the cortex (*cort*); *x*, xylem, and *p*, phloëm, arranged radially. After Bonnier and Sablon

2. **Drawing.** Be able to construct a drawing of a stem of a monocotyledon to bring out the contrasts between its structure and that of the stems of herbaceous dicotyledons examined above.
3. Summarize the differences between the stems of herbaceous dicotyledons and monocotyledons.

B. STRUCTURE OF ROOTS

Study transverse sections of large and small roots and compare their structure with that of herbaceous and woody stems of dicotyledons.

1. **Bark.** Do roots possess a definite bark? Has the bark (including tissues between epidermis and cambium) the same general layers as in stems? Are these layers similar in arrangement and structure in stems and roots?
2. **Xylem and pith.** Are these two regions the same in roots and stems? Compare young and old roots in this respect.
   a. Dead tissues of the xylem. Do you find ducts and fibrous cells? How are they arranged in roots? Are there annual rings?
   b. Living tissues of roots. Are these more or less abundant in roots than in stems? Stain fresh root sections with iodine to demonstrate this point.
3. **Cambium and phloëm.** Are these tissue layers present in the root section that you are studying? Are they as evident as in stem sections?
4. **Drawing.** Construct a drawing of a root in transverse section (no cells), to illustrate root structure. Label the tissue layers correctly.
5. **Summary.** Summarize the distinctive features of root structure as compared with that of herbaceous stems.

C. THE STRUCTURE OF THE LEAF

For the preliminary study of the structure of a leaf use thick leaves of *Narcissus* or onion, which are easily sectioned in a fresh state.

1. **Epidermis.** Peel or strip the epidermis from a leaf of the onion or *Narcissus.* Mount in water or dilute alcohol and study its cellular structure.

a. Low-power study. Are all the cells of the epidermis alike in structure and form? Do they have chloroplastids as a part of the cell contents? Do they differ in this respect?

b. A high-power study. Study the colorless and the green cells of the epidermis very carefully with a high power. Note the shape and structure of each kind of cell. How many green cells are grouped together? Are they separated by a solid wall or is there a pore between them?

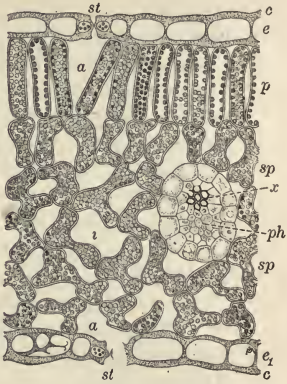

FIG. 16. Transverse section of a leaf

e, e_1, upper and lower epidermis with thick outer wall (*c*) and stomate (*st*); *p*, palisade cell layer with intercellular space (*a*) below the stomate; *sp*, spongy parenchyma with intercellular spaces (*i*); *ph*, phloëm; *x*, xylem of a vein in section. After Prantl

c. Drawing. Draw a few cells of the epidermis of the leaf accurately, indicating the detailed structure of the stomata and the surrounding epidermal cells.

2. **Leaf sections of a fresh leaf.** Study transverse sections of leaves cut from fresh material. Locate the main tissue layers of the leaf in such sections and note their general character. Use low power and dissecting lenses in the study of these thick sections. Is the green tissue favorably placed for receiving light rays? Do you find the veins and the epidermis?

a. Make a general drawing, omitting the cells, to show the position of the epidermis, green mesophyll, and veins of the section which is under observation.

b. Epidermis.

(1) Note its color, thickness, and extent as a covering of the leaf surface. What is the real form of the entire epidermal layer of the leaf you are studying? Do you find stomata? Stomata may frequently be recognized as darker places in the fresh epidermis. Details of the guard cells cannot be seen in such thick sections.

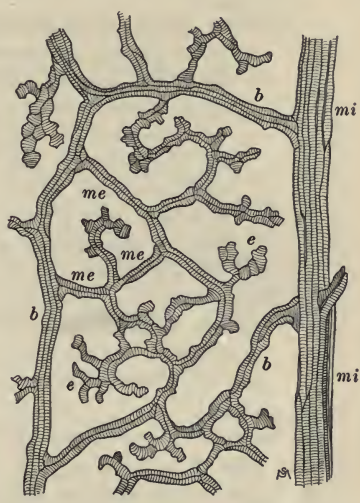

FIG. 17. Conducting cells (*tracheids*) of the veins of a leaf

mi, midvein; *b*, lateral veins; *e*, termination of veins; *me*, areas occupied by mesophyll cells in the living leaf. After Sachs

(2) What special structural feature of the epidermal cells insures against the loss of water? Would the same structural feature serve other protective functions? Search for sections of the guard cells and of the pores of stomata. Determine the peculiar cell character of the guard cells,—for example,

the relative thickness of the cell walls as well as the size and the living contents of the guard cells.

c. Mesophyll.

(1) Note the character of a mesophyll cell as regards cell wall and cell contents. Does each mesophyll cell come in contact with an intercellular space? What would be the advantage of such an arrangement? What is your conception of the intercellular system of a leaf? Is it a continuous aërating system or are the spaces seen in a transverse section isolated spaces? Do you find any intercellular spaces immediately above the stomata?

d. Veins. Study the structure of the veins. By what kind of tissue are the ducts surrounded? Is there a phloëm like that connected with the xylem of stems? What is the double function of the veins in a leaf?

e. The skeletal tissue. Study its distribution and the character of its cells.

f. Drawing. Construct an accurate drawing of a small portion of your section so as to include a large vein. Detail the tissues of the epidermis, mesophyll, veins, and skeletal structures.

SECTION IV. PHYSIOLOGY OF PLANTS

INDIVIDUAL AND CLASS EXPERIMENTS

Two classes of experiments are outlined below: namely, *individual* experiments, which are to be performed by each member of the class, and *demonstration*, or class, experiments, which are set up by an instructor, or by some member of the class, for observation by all members of the class. Both kinds of experiments should be written up and handed in as a part of the regular laboratory requirement. Unless otherwise stipulated, all experiments should be written up in the following order:

RECORDING OF EXPERIMENTS

1. **Object of the experiment.** State concisely the object of the experiment.
2. **Method.** State the method used in the experiment, drawing apparatus when necessary to make the method clear.
3. **Actual results secured.** State concisely the actual results secured. Do not include theories and conclusions.
4. **Conclusions.** What does the experiment seem to you to prove?

A. PHOTOSYNTHESIS

1. **The presence of starch in leaves of *Pelargonium* or a similar plant with white areas.** Individual experiment.
   a. Compare fresh leaves of *Pelargonium* with leaves which have been previously boiled and treated with alcohol. Give the reason for the difference in color. Be able to explain to an instructor.

b. Place a bleached and a fresh leaf in separate watch glasses and flood with iodine solution. After a half hour rinse the two leaves in water and place in watch glasses of water for observation. Test some starch with iodine in a watch glass. Compare the starch reaction with that of the leaf. Is starch present in *Pelargonium* leaves? If so, where is it located and where did it originate? How and when is the starch in a leaf used? Have you had any clue to the answer to this question in your work with woody stems?

c. Record the object, method, and results of, and the conclusions to be drawn from, the above experiments, as indicated above under Recording of Experiments. Include in the results a drawing of the bleached leaf, showing the distribution of starch.

2. Test as above leaves of young growing corn or bean plants about six inches high. Individual experiment.

a. Use two plants which have been in the dark overnight or for at least six hours. Why is this precaution necessary?

b. Expose one plant to bright sunlight for an hour or more and leave another in darkness. Remove a leaf from each plant, boil, extract chlorophyll with warm 80 per cent alcohol, and test for starch.

c. Results? Do the two leaves show a different reaction to iodine? If so, be able to state why. What important conclusions are to be drawn from this experiment?

d. Record your results and conclusion as prescribed above.

3. **Gaseous exchanges in water plants during photosynthesis.** Class demonstration.

a. Observe plants of *Elodea* (water weed) which are exposed under water to bright sunlight. Are bubbles

of gas given off? Shade the plant. Do the gas bubbles continue? Explain. Record the experiment by the usual method.

b. Can you suggest a method for testing the gas given off by *Elodea* and other water plants when exposed to sunlight? If so, perform the experiment as you have planned it.

c. Record object, results, and conclusions in the usual manner.

4. **Gaseous exchanges in land plants.**

a. Place three tubulated bell jars in three large plates or pans which will hold water. Narrow-necked bottles (Wolff-neck bottles are good) may be used instead of bell jars. Place in two of the bell jars, or bottles if these are used, vigorous leafy shoots of plants. If bell jars are used, pour water into the plates or pans until it rises an inch or more in each jar.

b. Lower into each jar or bottle a lighted candle, and cork tightly with a rubber cork or a vaselined common cork. How long does the air in the jars support combustion? Why do the candles go out? How does the burning of the candles change the composition of the air in the jars? Record answers to points (1) and (2) under *d*.

c. Put all of the above jars in sunlight and cover one containing a leafy plant so as to exclude light. After two or three hours lower lighted candles into each jar and test quickly to see whether the air in them will support combustion. Is there a difference in the air in the jars in this respect? Be able to explain any differences observed.

d. Record the experiment in the usual manner. Under Results indicate the composition of the air in the

three jars (1) before the candles are placed in them, (2) immediately after the candles cease to burn, and (3) at the close of the experiment, before the corks are removed. Explain also the daily gaseous income and outgo of the exposed and the covered plants in the two jars during the period of the experiment. How and why would they differ in this respect?

e. Considering the results of the above experiment, how do plants affect the air of a living room by day? at night? Is it healthful to have a large number of plants in a living room? Give reasons for your conclusions concerning this matter.

B. RESPIRATION

1. **Gaseous exchange of plant parts during respiration.** Individual experiment.

   a. Select two bottles or pint fruit jars with wide mouths. Put into one bottle or jar enough dry peas or beans to cover the bottom. In the second receptacle place a similar amount of germinating seeds after they have been sterilized in a weak formalin solution. Test the air in each receptacle with a burning match to see if it supports combustion. Cork air-tight and set aside for twenty-four or forty-eight hours.

   b. After the above period remove the corks and test the air again with a lighted match. Result?

   c. Write up the experiment, indicating the composition of the air in the receptacles at the beginning and at the end of the experiment. Indicate also the gaseous income and outgo of the seeds in each jar during the time of the experiment.

d. Class experiment. Treat green leaves, stems, buds, or flowers as indicated above for seeds. Observe and record results and conclusions at the end of the experiment as indicated under *c.* What precaution is necessary where green plant parts are used?

NUTRITION AND SEASONAL LIFE

1. Study the seasonal life of common plants like the potato, corn, onion or tulip, cherry tree, and locust tree.
   a. Compare the seasonal life of the annuals with that of the bean outlined in the text; that of the biennials with that of the white sweet clover; that of the perennials with that of the locust and the apple.
      (1) What provision does each plant make for wintering? for spring growth? for summer activities and storage? Are the same physiological functions characteristic of all plants at the same season in a similar habitat? Be able to state the main functions or activities characteristic of the plant in winter, spring, summer, and autumn.
      (2) Be able to construct drawings similar to those of the text, indicating the structures by which plants winter and perform the activities of the spring and summer seasons.
      (3) Summarize the dominant nutritive activities of plants in the different seasons. See Fig. 63 of text.

C. TRANSPIRATION AND WATER ASCENT

TRANSPIRATION

1. Record the loss of water from a leafy shoot placed in a graduate or in a potometer made from a burette. Class experiment.

a. Note and record temperature, general light intensity, and relative humidity at the time of taking each reading. Take records at convenient intervals for about three days.

b. Write up the experiment as usual. Under Results tabulate your readings to show temperatures, light intensity, and relative humidity, as well as the amounts of water lost at stated periods and for the entire period.

c. Summarize the main factors which have apparently caused variations in the rate of transpiration in your experiment at different periods.

2. Record the loss of water by transpiration from a potted plant, as for the previous experiment, and record results as explained above. Class experiment.

WATER ASCENT

1. **The path and rate of water ascent.** Individual experiment. Cut off leafy herbaceous shoots or stalks of celery under water and add eosin to make a strong colored solution, and observe as follows:

a. Rate of water ascent. If transparent stems of *Impatiens* or bleached stalks of celery are used, the progress of the colored solution may be observed in the stem or in the leaf veins.

(1) After from three to five minutes remove the stem from eosin and make cross cuts of it, beginning at the apex, until the coloration by eosin appears in the cross section. Measure the length of the stem traversed by the solution during the time it was left in eosin.

(2) From the above data determine the rate of ascent per hour. Compare with the rates of water ascent

given in the text. Would the eosin rise in the stem as rapidly as pure water? Record results.

b. Path of water ascent in the stem and leaves.

(1) Cut the stem lengthwise through a node and trace the path of the eosin from the main stem into the leaves and branches.

(2) Draw a transverse section and a long section of the stem, indicating the tissue in which the eosin solution moved. Did it pass up the ducts or in other tissues of the xylem and phloëm?

(3) Plot the path in the leaf veins and veinlets.

ECOLOGICAL RELATION OF PLANTS TO WATER

1. Make a list of 10 mesophytes, 10 hydrophytes, 5 xerophytes, and 10 tropophytes from the wild and cultivated plants of your own region. Be able to explain the gross structural adaptations of these plants to their habitat.
2. Are some of the above plants apparently not adapted to their present habitat? If so, how do you explain this? Be able to give the essential characteristics of the mesophytes, hydrophytes, xerophytes, and tropophytes of your region.

SECTION V. REPRODUCTION

A. SEXUAL REPRODUCTION

THE FLOWER AND ITS PARTS

Examine some large flower like that of the mandrake and note the nature and relation of its parts.

1. How many kinds of different parts or organs are there in the flower? How are they arranged with reference to each other? Does each set of organs form a circle, or whorl, like cyclic leaves on a stem, or are all parts of the flower spiral, like spirally arranged leaves? Do any portions of the flower resemble leaves in color, form, or venation?
2. Remove carefully the floral parts or organs on one side of a flower. Place the parts thus removed in a watch glass of water for future examination. Now examine the flower from which the parts have been removed.
   a. What is the nature of the floral axis to which the floral parts are attached? Has it nodes and internodes? Is it like the axis of a branch or bud in this respect?
   b. Observe again the relative position of the different sets of organs of the flower. Are the members of each set spiral or cyclic in arrangement? What kind of organ (or organs) terminates the floral axis?
   c. Does the flower resemble a bud in the arrangement of its organs on the floral axis? Does it seem to you possible that the flower was originally derived from a short branch or bud? What parts of the flower are nearly like leaves? What parts are highly modified?

3. Draw the entire flower as it appears on the side from which the parts have been removed. Indicate accurately in the drawing the form and relative position of the floral parts on the floral axis.
   a. Study the text and Figs. 215 and 84 and name the parts of the flower sketched above.
4. **The essential organs of the flower.**
   a. Anthers and pollen. Observe carefully with a hand lens and low power the dehiscence of the anther. Does the anther sac open crosswise or lengthwise to shed the pollen? Do you see the dustlike pollen grains issuing from the slit, or dehiscence line, of the anther? How many anther sacs are there in one anther? Draw a stamen greatly magnified to show the mode of dehiscence of the anther sac.
   b. Pollen. Dust some pollen on a slide and study its form and structure. Is the pollen grain a cell? Is its wall smooth or rough? Can you see any cell contents? Draw the pollen, exterior view, as it appears to you in your specimen.
   c. The pistil.
      (1) Observe the external parts of the pistil and note their form and structure. Observe the stigma carefully. Is it adapted to the reception and retention of pollen? Draw a pistil, including an enlarged view of the stigmatic surface, and name all its parts.
      (2) Cut a transverse section of the upper and middle portions of the ovary. Cut also a section through the style, if one exists. How does the ovary differ in structure at the different levels at which you have cut it? How is the wall of the ovary modified in the median, or middle, section of the

ovary? Are there budlike outgrowths from the enlargement of the ovary wall in your section? What is the shape of these buds, or enlargements? Draw the two or three sections of the ovary which you have made. Label the parts after you have studied the text and Fig. 220.

5. **The fruit.** Study both the external and the internal structure of the fruit of the mandrake or other plant examined. Do you find the same parts in the fruit as you did in the pistil? What forms the interior of the fruit? Where are the ovules? the placenta? the ovary wall? What relation has the fruit to the pistil? Define a fruit. Draw a sectional view of the fruit to show all of its parts in their proper relation. Label the parts, using the same terms as were used for similar parts of the ovary (see text discussion and Fig. 221).

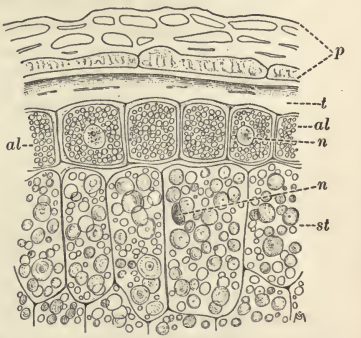

FIG. 18. Section of a portion of a wheat kernel *p*, pericarp; *t*, seed coat; *al*, aleurone, or nitrogenous layer of the endosperm; *n*, nuclei; *st*, starch-storing cells of the endosperm. After Strasburger

6. **Supplementary studies: gametogenesis, fertilization, and development.**

a. Microscopic structure of pollen. Mount large pollen grains taken from some liliaceous plant, like the

tulip, Narcissus, or Easter lily. Observe them carefully under low and high powers of the microscope.

(1) Does the pollen cell have one or more nuclei? Do different pollen cells differ in this respect? Do you see granular cytoplasm surrounding the nucleus in some pollen cells?

(2) Draw a pollen cell much enlarged. Indicate the granular condition (Fig. 85, *a*) of the cytoplasm and the relative size of the nucleus, or nuclei, in the cell. Label your figure correctly.

(3) *Study of pollen tubes.* If pollen tubes are available, study the structure and method of formation of pollen tubes. Draw a pollen cell and its pollen tube. Note and draw the structure of the tube and its cytoplasmic contents. If possible observe the nuclei in the pollen tube. This point is difficult to determine.

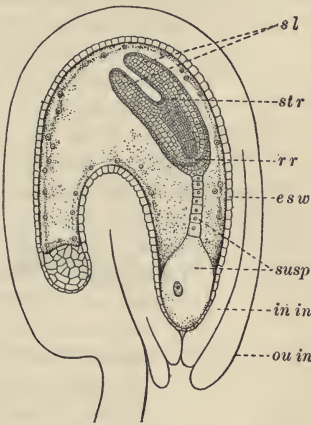

FIG. 19. Diagram of the ovule, embryo sac, and embryo of shepherd's-purse (*Capsella*)

ou int, outer integument; *in int*, inner integument; *susp c*, suspensor cells; *e s w*, embryo-sac wall; *r r*, root region; *st r*, stem region; *s l*, seed leaves. From Bergen and Caldwell's "Practical Botany"

b. The structure of the ovule.

(1) *Gross structure.* Dissect out the ovule from the ovary of some common plant into a drop of water on a slide. Mount and observe the essential parts of the ovule; namely, the funiculus, or stalk, the body of the ovule, and the micropyle. Ovules of the shepherd's-purse (*Capsella*), when treated with a weak solution of potash, will often show the outline of the embryo sac within the ovule. Draw one or more ovules to show the structure observed. Label.

(2) *Microscopic structure of the ovule.* If material is available, study thin sections cut through the ovule to show the embryo sac and micropyle; for example, in shepherd's-purse or mandrake.

(*a*) Determine the structure and thickness of the seed coats. Do you see the micropyle of the ovule? What is the nature of the large central light space of the ovule? Is there a nucleus in this space? Are there vacuoles and cytoplasm? Has this central space the structures of a cell?

(*b*) Study the structure and position of the embryo.

(*c*) Draw the sectional view of the ovule, indicating the micropyle, the cellular structure of the ovule coats, and the form and structure of the embryo sac and embryo.

POLLINATION IN PAPILIONACEOUS FLOWERS

1. **Inflorescence, or flower cluster.** Examine an inflorescence of some plant belonging to the pea family.

a. Parts of the inflorescence. Has the inflorescence axis the same parts as the stem axis below it; namely,

nodes and internodes? Where do the flowers originate on the axis? Is there any structure below the flower stalk corresponding to a leaf? To what part of an ordinary leafy shoot would a flower on the inflorescence axis correspond most nearly,—to a leaf a bud, or a branch? On what evidence do you base your conclusions? See Fig. 212 of the text.

b. The inflorescence and pollination. Are the open flowers at the apex or at the base of the inflorescence? Is the inflorescence an advantageous arrangement for securing cross-pollination, or the transfer of pollen from the anther of one flower to the stigma of another flower, by insects? Compare an inflorescence with solitary flowers in this respect. Sketch an inflorescence and a portion of the stem below it. Name the parts correctly.

STRUCTURE OF PAPILIONACEOUS FLOWERS

Structure of the Flower

Examine flowers of some member of the pea family and compare their structure with that of a simple flower like that of the mandrake.

1. **Perianth.** How many whorls, or sets, of organs in the perianth? Are the members of each whorl regular or irregular in form? How many parts in each whorl? Are the parts of each whorl united or separate? Remove the parts of the perianth and place them in their proper order on the table. Sketch the parts of the corolla.
2. **Essential organs.** How many stamens are there? Are they separate or united? How are the stamens related to the pistil? Study the form and external features of the ovary, style, and stigma. Study the style and stigma

with a hand lens. What is the nature of the stigmatic and stylar surfaces? Are they smooth or rough?

3. Remove the perianth from one side of a flower so as to expose the essential organs in their natural position.
   a. Sketch the essential organs accurately and indicate in outline the relation of the perianth to these organs.
   b. Make an accurate drawing of the pistil, indicating the position of the placenta and ovules and the peculiar structure of the stigma and style. What advantages are there for pollination in the structural relations of the style and stigma? Label all of the above figures accurately. See Fig. 89 of the text.

Cross-Pollination

Select a flower of some member of the pea family for the following experimental study of cross-pollination:

1. Press down the keel petals with the point of a pencil or with a dissecting needle. Result? Where would an insect need to alight in order to imitate the above action of the keel, stamens, and pistil? If an insect should visit a series of flowers like the one experimented upon, would cross-pollination be secured? Be able to explain.
2. Read the account in the text (p. 170) on cross-pollination in the common locust (*Robinia pseudo-acacia*).
   a. Does the flower upon which you experimented possess the contrivances of the locust flower for securing cross-pollination? If not, in what respect does it differ from the locust?
   b. Construct a drawing to show the relation of the anthers to the stigma and of both anthers and stigma to the keel, when the latter is depressed. Compare the figure with your first figure of the flower with one half of the corolla removed.

3. **The fruit and seed in members of the pea family.**
   a. Examine the fruit of the pea, bean, locust, or some other member of the pea family. Compare this fruit with that of the pistil already studied. Note the corresponding parts of fruit and ovary. Be able to define a fruit in terms of the pistil.
   b. Remove one half of the wall (carpel) of the fruit and observe the form and attachment of the seeds to the placenta. Sketch the inner view of the fruit or pod with the seeds. Label the parts of your sketch accurately, including the parts of the seeds. Use the same terms as those used for the pistil and ovules.
4. Examine seeds of beans or of the locust. How has the ovule changed to form the seed? What advantages are there in the changes? Do you find the scar on the seed caused by the breaking off of the funiculus? Do you find other marks near this latter scar? Draw an exterior view of the seed on the side of the hilum, or scar, caused by the removal of the funiculus. Label accurately.
5. Cut thin sections from the cut surface of the cotyledon of a bean. Stain with iodine. Result? What is the function of the cotyledons? What kind of reserve food is most prominent as revealed with iodine? Draw a portion of the section (Fig. 18).

SUPPLEMENTARY STUDY

Study some assigned flower or flowers with reference to devices for securing cross-pollination. Construct drawings to indicate the particular devices for pollination in the flower or flowers examined.

PART II. THE PLANT GROUPS

SECTION VI. THALLOPHYTES (ALGÆ AND FUNGI)

A. THE ALGÆ

PROTOCOCCUS (*PLEUROCOCCUS*)

1. **Habit and Habitat.** Note the appearance of *Protococcus* on bark, boards, or stones. Has the green incrustation any definite form or structure comparable to that of the higher green plants? Do you see any evidence of roots, stem, or leaves? Do you know whether *Protococcus* ever lives in water, like the other fresh-water algæ? Is *Protococcus* on bark or stones xerophytic or mesophytic in habit and habitat?
2. **Structure.** Scrape off a little of the green incrustation formed by *Protococcus* in a drop of water on the center of a glass slide. Be careful not to remove pieces of bark or dirt with the plants. Cover and press out gently under the cover glass with a dissecting needle. Examine with the low power of a compound microscope.
   a. What is the nature of the green masses observed under a low power? Are they composed of cells? Do you find any single green cells? What constitutes a *Protococcus* plant? Is it unicellular or multicellular? Do you find chloroplasts, cell wall, etc.?
   b. Sketch two or three green masses to show their structure as you observe them. Label the parts in terms of cells and cell structures.

3. **Reproduction.** Study the method of reproduction outlined and illustrated (Fig. 115) for *Protococcus* in the text.
   a. Observe three or four stages in reproduction from your mounts of *Protococcus.* Is this a vegetative or a sexual method of reproduction? Is it a rapid or a slow method? What becomes of the loose colonies formed by reproduction when the plants are exposed on bark, boards, or stones?
   b. Sketch three or four stages in the reproduction of *Protococcus,* beginning with a single-celled plant.
4. **Dissemination.** How does *Protococcus* spread from tree to tree or from any one habitat to another? How does it form a large incrustation from the first few cells in a new habitat? Why does it usually occur on the north side of trees and fences? Why is it more abundant on rough than on smooth surfaces?
5. **Nutrition.** What is the source of the water, gases, and salts which constitute the raw food materials for *Protococcus* plants? How are these materials absorbed? Are they made into foods and used by *Protococcus* as they are in a tree or a geranium plant? Be able to indicate the income and outgo of food materials and wastes in *Protococcus* plants.
6. **Summary and discussion.** Discuss briefly in your notes the main points indicated above concerning the structure, reproduction, dissemination, and nutrition of *Protococcus.*

CHLAMYDOMONAS

If *Chlamydomonas* is available for study, compare it with *Protococcus* in structure, reproduction, and dissemination. Note particularly the rate and mode of movements in active *Chlamydomonas* plants. The brick-red eyespot and the cup-shaped chloroplast may be observed in forms which have come to rest.

SPIROGYRA (WATER SILK)

1. **Habitat and habit.** Observe plants of the common green scum floating in an aquarium or on ponds in the open. Remove a small portion of the green mass to a watch glass. Separate somewhat and examine with a hand lens and the low power of a compound microscope.
   a. Is the green mass composed of one plant or many? What is the nature of the *Spirogyra* plant? Has it roots, stems, or leaves? How does it differ from plants of *Protococcus*?
   b. Sketch one or two *Spirogyra* plants as seen under a low power. Name all structures observed.
2. **Cell structure.** Study the cells of a *Spirogyra* plant under high power. Are the cells composing the plant all alike or are they differentiated for different functions? Note the bandlike chloroplasts. How many are there in each cell?
   a. Chloroplast and pyrenoids. Compare fresh and stained plants of *Spirogyra* in the study of the pyrenoids. Read the text concerning the structure and function of the pyrenoids.
      (1) Stain fresh plants with iodine solution after they have been exposed to sunlight. Does the starch sheath of the pyrenoid contain starch? In what part of the pyrenoid is the starch stored?
      (2) Compare your specimen with a *Spirogyra* plant which has been specially stained and mounted for study. Such preparations often show the pyrenoids and nucleus with great distinctness.
      (3) Sketch a portion of a chloroplast and two or more pyrenoids greatly magnified. Indicate the starch sheath and central granule of the pyrenoid and the form and structure of the chloroplast.

b. The nucleus. Study the nucleus in stained material. What is the form of the nucleus and where is it located in the cell? Is it connected with the pyrenoids? Study several cells with reference to these points. Draw a *Spirogyra* cell to show the nucleus in its proper position and in its connections with the pyrenoids. Construct a transverse section of a *Spirogyra* cell cut through the nucleus. Label all parts correctly. See Fig. 118 of the text.

3. **Reproduction.**

a. Conjugation of the filaments.

(1) Study early conjugating plants with a low power. Observe the method of union of the filaments. Do you find different stages in the formation of protrusions from the cells and in the formation of connecting tubes? Observe whether the union of the filaments affects the cytoplasm of the uniting parent cells.

(2) Draw stages representing the union and conjugation of the filaments in *Spirogyra.*

b. Formation of the gametes.

(1) Study plants in which gametes are forming. Observe as many stages in gamete formation as possible in the material at your disposal. Do you find male gametes forming before the female gametes in cells united by connecting tubes? What is the method of gamete formation? What is a gametangium? Consult the text for the meaning of this term. How does it differ from a gamete? What are the structural parts of each?

(2) Draw gametangia in which gametes are forming. Indicate as many stages in gamete formation as you find. Label gametangia and gametes.

c. Fertilization.

(1) Observe stages in which gametes are fusing to form zygotes. What is the difference in the behavior of the two gametes during fertilization? On what basis can one be designated as male and the other as female?

(2) Draw stages in fertilization as observed.

d. The zygote.

(1) Study cells in which zygotes are formed. What is the structure of the zygote cell? Distinguish between pyrenoids and nuclei in the zygote cell. Stain zygotes with iodine. What kind of reserve food does the zygote contain? When and for what purpose will this food be used? Draw two or three zygotes to illustrate their cell structure.

4. **Life history of Spirogyra and Protococcus.** Construct a graphical life history of *Spirogyra.* Is it possible to construct a similar graphical history for *Protococcus*? In what fundamental respects does the life history of *Spirogyra* differ from that of *Protococcus*?

VAUCHERIA (GREEN FELT)

Select fruiting specimens of some species of *Vaucheria* for study. Observe the following points regarding its habitat, habit, and structure:

1. **Habit.** In what respect is *Vaucheria* peculiar in its general structure? Is it a simple or a branched filament? Is the plant body differentiated into root and shoot? What is its general microscopic structure? Is it unicellular or multicellular? What kind of chloroplasts has it?

2. **Sexual reproduction.** Mount fruiting plants of *Vaucheria* after teasing them apart with dissecting needles in a drop of water. Search for reproductive branches with a low power.

   a. Female gametangia and gametes. Search for greatly swollen and shortened lateral branches representing the female gametangia.

   (1) Do these reproductive branches differ from the ordinary branches of the plant body except in size? What is the nature of the protoplast and of the embedded chloroplasts in these reproductive branches? Do you find a projecting beak, or rostrum, at one side of the reproductive branch? It is at this point that the cell wall of the gametangium breaks down and allows the male gamete to enter the egg.

   (2) In properly prepared material the nature of the protoplast and the location of the chloroplast and nucleus may be seen. Observe carefully with the high power.

   b. Male gametangium. The male gametangium is usually represented by a curved branch near the female gametangium.

   (1) Note the nature of the protoplast of the male gametangium. Contrast it with that of the female. Male gametes cannot usually be found in *Vaucheria*. If they have been expelled, the gametangium looks light-colored and empty.

   (2) Draw a portion of a plant bearing male and female gametangia. Detail the female gametes.

3. **Vegetative and asexual reproduction.** Vegetative reproduction occurs in *Vaucheria* by means of nonmotile reproductive branches which are merely swollen, club-shaped

lateral branches, bright green in color. Motile, free-swimming spores or zoöspores are also formed in some species as asexual bodies.

a. Vegetative reproduction. Search for the club-shaped branches with a low power. How are they formed? How do they become free from the mother plant? How would they grow into a new *Vaucheria* plant? Do you find free productive branches in your material?

b. Asexual reproduction by zoöspores. These are difficult to demonstrate in *Vaucheria* except in unusually favorable material. Draw any stages of asexual reproduction which you have succeeded in demonstrating.

4. **Life history.** Write a graphical life history of *Vaucheria* similar to that constructed for *Spirogyra*. In what respect are the two life histories similar? In what respects different? Which alga has the higher type of reproductive process? Explain. What is the function of vegetative and asexual reproduction as contrasted with sexual reproduction in a plant like *Vaucheria*?

ŒDOGONIUM

1. **Habit.** Study plants of *Œdogonium* and compare them with *Spirogyra* and *Vaucheria* as regards form and structure. How do the cells differ in form and contents from the other algæ studied? Draw a plant of *Œdogonium* to illustrate its habit and cell structure.
2. **Reproduction.** Study plants in which the gametes are forming.

a. Female gametangia and gametes. Observe one or two stages in the formation of female gametes from single cells of the filament as described in the text. How is the female gamete formed? What is its structure?

Sketch one or two stages in the formation of female gametes. Label accurately.

b. Male gametangia and gametes. If material is available, study the male gametangia and gametes as described and figured in the text. Sketch stages demonstrated, and label.

c. The zygote. Study the zygote of *Œdogonium*. Is it adapted, by its cell structure, for carrying the plant over an inclement period? Note its form and contents. Draw.

d. Asexual reproduction. The asexual reproductive process is difficult to demonstrate with beginning classes and should be studied from the text and figures.

e. Life history. Write a graphical life history of *Œdogonium* similar to that outlined for *Spirogyra*. How is this history adapted to seasonal changes?

GENERAL STUDY OF FRESH-WATER ALGÆ

1. Examine water containing free-floating algæ, or algæ attached to objects covered by water. If algæ are scraped from surfaces, they should usually be separated on the slide with needles or by gently tapping the cover glass with needles. Mount in fresh water and examine first with low power.
2. **Form and structure.** Note the number and kinds of algæ living together in one place. How many distinct kinds or species of algæ can you distinguish in the water you are examining? Are there unicellular forms? many-celled forms? Have any species the power of movement? Note differences in the form or color of the chloroplasts in different species.
3. **Reproduction.** Are any of the species that you are examining reproducing either vegetatively, asexually, or

sexually? If so, trace out the stages of reproduction found in your material.

4. Sketch the different species of algæ observed and show stages in reproduction where such are observed.

FUCUS VESICULOSUS (MARINE ALGA)

1. **Habitat and habit.**
   a. Is the water habitat of *Fucus* more or less stable and permanent than that of fresh-water algæ? Do you know of fresh-water forms which attain to the size or the structural differentiation of *Fucus*? Is there a reason, based on difference of habitat, for this difference in habit between *Fucus* and fresh-water species? Note the differentiation of the plant body into root and shoot portions. What is the function of the root and shoot? How is each part adapted to its special function? How is it adapted to photosynthesis? to resistance to waves and water currents? to protection from dessication, or drying, when exposed at low tide?
   b. Study the form and branching of *Fucus*. Can you determine how the very regular mode of branching occurs? Where are the growing points? Is there anything like a bud? Observe the swollen floats which buoy the plant up in water.
   c. Sketch a portion of a *Fucus* plant to show its habit and mode of branching.
2. **Microscopic structure.** Examine thin sections cut across a *Fucus* plant. What is its general structure? Is there an outer protective epidermis? Where is the chlorophyll layer or layers? Does the chlorophyll-bearing layer look green? Explain the color of this layer. What kind of tissue occupies the center of the branch as

shown in the section? Is *Fucus* composed of a true cellular tissue like a geranium? Make an outline drawing of the section, shading in the chlorophyll-bearing layer. Detail a few cells of each layer to show the cellular structure.

3. **Reproduction.**

a. Reproductive branches. Read the text description of reproduction in *Fucus*.

(1) How are the reproductive branches distinguishable from the ordinary vegetative branch tips? Find the male reproductive branches, covered with a yellow exudation of slime containing the male gametes. Learn to recognize the female branches by the greenish exudation of slime containing female gametangia.

(2) *Ostia, or pores.* Observe *ostia* with a hand lens on the surface of the reproductive branches or with a low power in thin horizontal surface sections of reproductive branches.

b. Gametes and gametangia (living material).

(1) *Male gametangia and gametes.* Touch the surface of a slide with male branches which are exuding yellow slime. Mount and observe the saclike male gametangia containing male gametes, which look like yellow dots. Look for male gametes free from the gametangia on the slide. Can you distinguish the movement of these male gametes? their form and structure? A brick-red spot, "the eyespot," is usually visible.

(2) Draw male gametangia and gametes somewhat magnified.

(3) *Female gametangia and gametes.* These may be obtained as in the case of the male gametes. Note

the saclike gametangia inclosing from four to six visible divisions of the contained protoplast. These are the future gametes. Search for other specimens in which eight eggs, or female gametes, are rounded up inside of the gametangium membrane. Find also free eggs which have been liberated, as they are in nature, from the gametangium. What is the structure of the female gamete? How does it compare in size with the male gamete? Is the female gamete motile? What advantage is there in the small male gametes and the large female gamete? Draw a gametangium containing developing gametes and a free female gamete.

c. Fertilization. The swarming of gametes around the eggs may often be observed if the two gametes are mounted together in sea water. The act of fertilization is too difficult for observation by the beginner.

d. Female gametangia and gametes. Observe prepared sections cut through female receptacles and stained. Note the flask-shaped receptacles from the walls of which the oögonia and paraphyses grow out into the cavity of the conceptacle. Study different stages in the formation of the female gametangia and gametes. Do you find small gametangia with a single nucleus and cytoplasm? Search for other stages in which there are many nuclei. Find stages in which cell walls have been formed separating the cytoplasm of the oögonium into eight gametes. Draw the stages of the gametangium observed, illustrating different stages in the formation of gametes.

e. Male gametangia and gametes. Observe sections cut through male reproductive branches of *Fucus.* Are the gametes visible within the gametangia? How do

they compare in number and size with the female gametes? Were the male gametes formed like the females, by cell and nuclear division? Draw.

f. Life history. Write a graphical life history of *Fucus* similar to that of *Spirogyra* and *Vaucheria.*

B. THE FUNGI

YEAST

1. **Composition of compressed yeast.**
   a. Method. Remove a small portion of compressed yeast to a slide and mount in a drop of water, separating well with needles. Add weak iodine solution and observe with low and high powers of the microscope.
   b. Observation. Do you find indications of the presence of starch in yeast cakes? Can you distinguish the minute yeast plants looking like dots under low power? Examine these structures with a high power. What is the structure of a yeast plant? Contrast it with an alga like *Protococcus.* In what respects are the two plants similar? In what respects are they different? Why is the yeast cake not made up from pure yeast plants?
   c. Make a drawing to indicate the composition of compressed yeast.
2. **Cellular structure.**
   a. Method. Cultivate yeast by adding about 1 g. of compressed yeast cake to 15 cc. of a sugar solution made up as follows: to 100 cc. of water add 20 cc. of common molasses, or make up a 10–15 per cent sugar solution in water. Keep the sugar solution at about 25°–28° C. after adding the yeast in the above proportions. After vigorous growth and fermentation have begun, add a drop of the solution to a glass slide and cover.

b. Structure of the growing yeast plant.

(1) Study a mount of the above yeast solution with low and with high powers of the microscope. Is the yeast plant unicellular or is it composed of more than one cell? Are all the yeast plants on the slide the same in size and in cellular structure?

FIG. 20. Various kinds of wine and beer yeasts

a, *b*, wine yeast (*S. ellipsoideus*) (*a*, young and vigorous; *b*, old (1) and dead (2)); *c*, *d*, beer yeast (*S. cerevisiæ*) (*c*, bottom yeast; *d*, top yeast). After Marshall

(2) Select a large unicellular plant and observe its minute structure. Is the yeast cell like a root-tip cell? How does it differ from the cell of an alga like *Protococcus*? What fundamental nutritive process, performed by *Protococcus*, is impossible for yeast plants? Draw and name the parts of a large yeast cell.

(3) How do the small yeast cells differ from the large cells in structure? Draw a small yeast cell and compare with the large cell drawn above.

3. **Reproduction by budding.**
   a. Do you find yeast plants with two cells joined, namely, one large cell united with a small cell? Observe a number of these cases of two-celled or three-celled plants. Are the two or three united cells always unlike in size? Can you determine how these united cells originate from single-celled plants?
   b. Draw a series of two-celled yeast plants representing differences in size between the constituent cells. Can you now determine the method by which the yeast plant reproduces itself by budding? How does this method of reproduction differ from that found in *Protococcus*? Is it a sexual or a vegetative method of reproduction?
   c. Observe, if possible, wild yeasts in cider or in fermenting apples and make drawings to show their structure and mode of reproduction.
4. **Fermentation experiments.** Select two flasks of equal size and into one pour enough water to cover the bottom. Into the other flask pour an equal amount of actively fermenting yeast solution.
   a. Test both flasks for oxygen and carbon dioxide with a flame, with limewater, or with barium hydroxide. Set aside for an hour, keeping both flasks at a uniform temperature of 25° C. At the end of an hour test as above for oxygen and carbon dioxide. Result?
   b. Write up the above experiment in your notes, indicating the object, the actual results observed, and your conclusions concerning what was proved with reference to the nature of fermentation by yeast. See account of fermentation in the text.
   c. Fill two fermentation tubes with yeast solution. Keep one at 25° C. and the other at a much lower

temperature. Observe the two tubes every fifteen minutes or at such intervals as you find necessary. Results? How do you explain the differences observed in the two tubes? At the end of an hour test the two tubes for carbon dioxide. Result? Write up the above experiment in terms of object, method, results, and conclusions to be drawn concerning the nature of fermentation. Indicate method and results by drawings.

5. **Nutrition.** Draw a diagram of a yeast plant greatly magnified. Indicate the income and outgo of the yeast cell, comparing its nutritive processes with those of *Protococcus* and a specialized green plant. Contrast briefly the nutrition of yeast and that of green plants like *Protococcus* and *Geranium* (see Fig. 2 of the text).

BACTERIA

Class Experiments

1. Expose a sterilized culture dish containing nutrient gelatine, agar-agar, or other suitable substance for bacterial growth in the classroom or laboratory for fifteen or twenty minutes. Expose a second culture dish out of doors or in a quiet room. Cover and observe after the cultures have remained for twenty-four hours in a warm place.
   a. Are there colonies of bacteria formed on the culture media in both cultures? Is there any difference in the number and kinds of colonies in the two dishes? How do you account for any differences observed?
   b. Study the colonies with a hand lens or with a low power of a compound microscope. Are there differences in the size, form, or color of the different colonies? Can you account for such differences?

c. Draw the colonies of one culture dish, indicating their distribution, size, and form.

d. Conclusions. State your conclusions concerning the following points:

(1) How do you account for the difference in the growth of bacterial colonies in the two culture dishes exposed to the air in the two different situations?

(2) How are bacteria evidently distributed? Why should one avoid crowded rooms in time of disease epidemics?

(3) How do you account for the differences in the appearance of different bacterial colonies?

2. Expose a sterile liquid culture medium in a test tube to the air as in the first experiment. Observe for several days at successive class exercises. Note any changes in the fluid which appear from day to day.

Microscopical Examination of Bacteria

1. Remove a small portion of a colony from one of the culture dishes in experiment 1 to a drop of water on a glass slide and cover.
2. Prepare a similar slide from the liquid culture in experiment 2.
3. Observe these preparations first with a low power and then under the high power of a compound microscope.

a. Form types of bacteria. Consult the text figures and discussions and observe as many of these forms of bacteria as you can find in your preparations. Do you find coccus, bacillus, and spirilla form types? Note the great variation in form and size of the bacteria.

b. Movements. Do you find bacteria with independent powers of movement? What is the nature of this movement? The motor organs, cilia or flagella, can

only be seen with very high powers in stained preparations. Omit unless such preparations are available.

c. Cell division. Do you see any bacteria in which the cells are dividing? Consult Fig. 135 of the text, and the discussion on vegetative reproduction in bacteria.

FIG. 21. Form types of bacteria

a, types of bacilli; *b*, types of micrococci; *c*, types of spirilla. After Williams From Marshall's "Microbiology"

d. If stained preparations of bacteria are available, study the structure and form of bacteria in such preparations.

e. Drawings. Draw the form types of bacteria observed.

f. Bacteria of the teeth. Scrape the teeth with a sterilized needle or scalpel. Sterilize first in a flame or in strong alcohol. Mount and observe. Do you find more than one form of bacterial cell in your preparation? How many do you find? Make a drawing of the bacteria found on the teeth.

MOLDS

General Nature of Molds

Examine molds growing on various substances in the laboratory and note the following points regarding their habitat, habit, and general structure:

1. **Habitat.** Upon what kinds of substances do molds grow? Are these substances sweet or sour? acid or alkaline? solid or liquid? How would the income and outgo of molds in the form of gases, liquids, and solids compare with that of a green plant like *Protococcus* or a *Geranium*? Do molds differ in the above particulars? Compare the income and outgo of a mold on bread with that of yeast and *Protococcus*. Be able to point out similarities and differences in the habitats, and in the substances derived from them, in the three cases cited.
2. **Habit.** Is a mold plant on bread or apples differentiated into organs or tissues like a higher plant? See Figs. 139 and 140 of the text. Do different species of molds show differences in color or structure? To what great group of green plants are molds most nearly related in their general structure and differentiation? In what important respect do they differ from this plant group?
3. **Gross structure and growth.**
   a. Growth (use hand lens). Examine patches of mold on apples, bread, and other media with naked eye and hand lens. Do the patches of mold observed seem to have any definite method of spreading by growth? Can you account for the circular appearance (Fig. 143 of text) often observed in patches of mold? Are some patches colored? Where is the colored portion?
   b. Remove some of the colored and colorless portions of different kinds of molds to different slides and mount

the material from each mold separately in water or in a mixture of alcohol and glycerin. Study the structures found in the colored and colorless portions of your mounts. What do you conclude as to the nature and function of these colored and colorless portions of molds? Are all molds which you examine alike in the general structure of colored and colorless parts?

c. Draw diagrams to illustrate the structures found in the colored and colorless parts of various molds. See text and figures on black and blue-green molds.

4. **Nutrition of molds** (for example, apple mold).

a. Method. Remove some of the pulp from a decaying apple with needles or the point of a scalpel and place on the center of a glass slide. Add eosin solution and crush out gently under a cover glass. The mold filaments, if present in the apple, will stain red with eosin.

b. Observation. Do you find mold filaments (hyphæ) among the apple cells? What is their function? their structure? How are they related to the white aërial mycelium and to the colored spores on the outside of the apple? Into what parts is the body of the apple mold divided? What is the functional relation of these parts? What kind of food would the mold secure from apples? How would it absorb it? Compare the income and outgo of apple mold with that of the wild yeasts in apple or in cider. Draw a portion of the apple mold as it appears within the apple. Include the cells of the apple pulp surrounding the hyphæ.

5. Summarize briefly the distinctive characteristics of molds observed under the above topics, namely, Habitat, Habit, Gross Structure and Growth, and Nutrition.

SPECIAL STUDIES OF MOLDS

Rhizopus Nigricans (Black Mold)

THE MYCELIUM AND NUTRITION

1. **Spores and spore germination.** Study spores which have been growing on prune juice or some other nutrient medium for different lengths of time; for example, twenty-four, forty-eight, and seventy-two-hour periods.
   a. *Early stages in spore germination.* Use cultures which have been grown from twenty-four to thirty-six hours at 25° C.
      (1) What is the earliest stage of spore germination that you can find? What change takes place in the form and structure of a spore when it begins to germinate? Does the entire spore cell elongate, or only certain portions of it, to form the beginning of a hypa or mold filament? Do you find branched hyphæ growing from spores? Note the structure of the longer hyphæ, including details of cellular structure. Are there vacuoles? Is there a cytoplasmic sac or is there solid cytoplasm in the young hyphæ? (The nuclei of *Rhizopus* cannot be seen in fresh material.) Is the hypha produced by spore germination unicellular or multicellular?
      (2) Draw two or three stages in spore germination, to show the spore, the progressive growth of a hypha from a spore, and the cellular structure of the hyphal cell.
2. **Development of the mycelium.** Study later stages in spore germination from cultures which have grown for forty-eight and seventy-two hours.

a. Note the changes in the hyphæ produced after a longer period of growth. Are they branched or unbranched? unicellular or multicellular? Have they the same structure as in the earlier stages noted above? Is the spore still visible? Draw two or three of these older stages in spore germination. Label correctly.

b. Observe the mycelium of *Rhizopus* growing on bread or some other medium. How was this mycelium produced? How related to the branched hyphæ noted above as a result of spore germination? How do you account for the origin of a mycelium on moist bread or in a moist chamber upon which no spores are artificially sown? Is there a submerged mycelium within the nutrient medium and an aërial portion exposed to the air? What is the function of the two parts of the mycelium? See text and Fig. 140.

3. **Nutrition.** How does *Rhizopus* differ from apple mold in the nature of its habitat? Are the foods of its habitat solid or liquid? In the case of *Rhizopus* growing on bread, how does the fungus absorb and use the starch of the bread as food? Contrast the nutrition of the apple mold and that of *Rhizopus* growing on bread.

REPRODUCTION

1. **Spore formation by sporangia.** Observe a mycelium upon which round balls, or sporangia, begin to appear (Fig. 139 of text). Place a patch of this mycelium with light-colored sporangia on a slide and observe with a low power without mounting.

a. What is the relation of the sporangia to the hyphæ? How are the sporangia related to the hyphæ of the mycelium? Are they formed by any special hyphal branches? Consult the text and Fig. 140.

b. Mount the above specimen in glycerin and alcohol and determine the relation of the sporangia to the hyphæ. What is the structure of a sporangial head? What is the nature of the contents of the young, light-colored sporangia? Consult Fig. 141 of text.

c. Read the text on asexual reproduction and spore formation in *Rhizopus*. Demonstrate as many of the stages of spore formation described in the text as you can.

d. Draw at least two stages of young, light-colored sporangia, including one in which spores are being formed.

2. **Mature sporangia and spores.** Study mature sporangia and note the columella, the sporangium wall, and the spores. What is the color and structure of the hypha which bears mature sporangia? Do you find the stolons and rootlike hyphæ connected with the hypha which bears the sporangium? See the text under Habit of *Rhizopus*. Draw a mature sporangium and show its connection with the main mycelium. Indicate stolons and rootlike outgrowths at the base of a sporangium-bearing hypha.
3. **Sexual reproduction.** If material is available, demonstrate stages in the sexual process of *Rhizopus*. Read the text on sexual reproduction. Demonstrate suspensors, gametangia, and zygotes, if seen in your material. Draw stages observed in sexual reproduction. Label correctly.
4. **Life history.** Write a graphical life history of *Rhizopus* similar to that already outlined for *Spirogyra* and other green plants.

Penicillium and *Aspergillus*

1. **Habitat and habit.** See the general nature of molds previously studied.
2. **Mycelium structure.** Remove small portions of the mycelium of a blue mold, mount, and study. Has it the same

structure as that of *Rhizopus*? Is it unicellular or multicellular? Note the structure of the hyphæ. Draw a small portion of the mycelium of a blue mold, to differentiate it from the mycelium of *Rhizopus*. Label correctly.

3. **Spore production.** Read the description of spore formation in *Penicillium* and *Aspergillus* (Figs. 144 and 145) in the text. Observe spore-bearing cultures of these molds as for *Rhizopus*. How do these molds differ from *Rhizopus* in their method of spore formation? How does *Penicillium* differ from *Aspergillus* in this respect?
4. Draw appropriate diagrams to express the methods of spore formation in *Penicillium* or *Aspergillus*. State concisely the difference in the method of spore formation in *Rhizopus* and the blue molds.

MUSHROOMS AND THEIR ALLIES

Mushrooms

1. **Habitat.** What is the habitat of mushrooms? Be able to name a number of habitats for mushrooms and their allies, the bracket fungi. What forms a common ingredient, or component, of the soil in all mushroom habitats?
2. **Habit and parts.**
   a. What are the parts of a common mushroom? What are the submerged portions in the soil, log, or other mushroom habitat? See complete specimens for this, including subterranean parts. What is the general form, texture, and color of the aërial parts? Observe the underside of the umbrellalike aërial portion. What do you find? What is the function of these structures on the underside of the umbrella?

b. Examine mushrooms of different ages. Is the color of these plates, or gills, the same in young and in old specimens? Compare the color change which you observe with that of molds. What is the function or use of the plates, or gills?

c. Bisect a mushroom vertically through the umbrella and its stalk. Study the relation of the gills to the umbrella. Draw the cut surface of the mushroom and include the subterranean and the aërial parts. (The subterranean portions may be drawn from specially prepared material if they are not available in the laboratory specimens.) Read the paragraph in the text and consult Fig. 147 on the parts of the mushroom. Label correctly the parts of your figure showing the habit of the mushroom.

3. **Nutrition.** State concisely the function of each part of the mushroom drawn above. Indicate the income and the outgo of the mushroom in gases, liquids, and solids in connection with the above figure or in an outline figure similar to Fig. 2, Part I, of text.

4. **Growth and expansion of mushrooms.** Study a series of mushrooms of different ages. What changes in the size, form, and relation of parts do you find taking place in mushrooms from young to mature stages? What is the apparent function, or use, of these changes? Draw a series of diagrams to illustrate the growth stages of a mushroom and discuss briefly the function, or use, of the changes indicated by your drawings.

5. **Structure.** Tease out on a slide portions of the stipe of a mushroom. Mount and study. Is the mushroom cellular like a higher plant, or is it an aggregation of hyphæ? Contrast the structure of a mushroom and that of a mold. Make drawings to indicate the structural elements of the mushroom.

6. **Spore formation.** Select spore-forming lamellæ of some species of *Coprinus*. Peel off a small portion of the spore-bearing surface and mount in water for study.
   a. Observe with a low power the spore-bearing surface of the lamella. Do you find brown spores in groups of four scattered over the surface of the lamella? Do you find basidia and paraphyses as described in the text and illustrated in Fig. 148, *c*?
   b. Draw a portion of your section to bring out the above points.
   c. Examine the edges of your specimen for basidia bearing sterigmata and spores. If not seen, tease the specimen in pieces with dissecting needles and observe the edges of the pieces. Do you find basidia with four sterigmata and young spores, and basidia with sterigmata and brown spores? How are these spores formed at the ends of the sterigmata? How are they shed? Draw a basidium with sterigmata and spores.
7. **Sections.** If basidia and spores are not found satisfactorily in the above material, sections of the lamellæ may be used.

Puffballs

General appearance, structure, and reproduction

1. Examine puffballs in two or three stages of development (Fig. 150) to determine the character and limits of the gleba and peridia. Note the changes in these two layers as the puffballs mature.
2. Examine the contents of mature puffballs. Some puffballs have indurated fibers, or hyphæ (the capillitium), formed in the gleba in connection with the spores.
3. Construct a drawing to show the relation of gleba and peridia. Draw spores and capillitium.

Rusts

1. Examine leaves of cereals or other plants on which the different kinds of spores of a rust are borne. Can you see differences in color or form of the different kinds of rust spores? Are the spores borne in groups or masses? Where is the mycelium from which these spores originated? How do the spores become exposed to the air? On how many and what kinds of hosts are the different kinds of spores borne?
2. Draw the stem or leaf surfaces on which spores are borne showing the groups of spores, or sori, of each kind produced by the species being studied. Name the host and the kind of spore in each drawing.
3. Examine the different kinds of spores of the rust microscopically. How do they differ? How are they adapted for distribution and wintering?
4. Draw each type of spore in some detail.
5. **Life history.** How many hosts are infested by the rust you are examining? What are the spring, summer, and winter spores? What is the function of each in the life history?

Smuts

1. Examine corn or other cereals infested with smut. Tease out some of the dark mass on a slide and examine microscopically. What is the composition of these dark smut masses? Draw some smut spores. Where is the plant which gave rise to the spores? Is it a parasite? How do the spores become exposed to the air? When and how do these spores infect a new crop?

Lichens

Select lichens growing on bark or stones and observe the following points:

1. **Color of upper and under surface.** Moisten lichens and note any change in color. What gives the peculiar color to lichens? Does the composition of the compound plant explain its peculiar color?
2. **The form of lichens.** Observe with hand lenses the lichens on bark, rocks, etc. Do you find different kinds, or species, of lichens recognizable by differences in size, color, and form? See the kinds of lichens on the display table.
3. Draw one or two lichens to illustrate their form.
4. Note the fruit cups, or apothecia, on the surface of some of the lichens. These cups (Figs. 156 and 157 of the text) are formed of spore sacs (asci) which bear spores of the fungus partner of the lichen. Draw apothecia to show their form and distribution.
5. **Structure of the lichen.** Moisten a small piece of a lichen thallus and tear in pieces in a drop of water on a slide. Cover and crush out under a cover glass. Observe the fungus hyphæ and the algæ which compose the plant body.
   a. *The algæ.* Note their form, color, and relation to the fungus hyphæ. The latter grasp the algæ with minute branches and absorb food from them. Are the algæ multiplying by division?
   b. *The fungus portion of the lichen.* Observe the hyphæ of the fungus. What is their structure? Draw the algæ and fungus mycelium comprising the lichen.
6. **Summary.** Summarize the work of the two partners, the fungus and the alga, in the life of the lichen.

Lilac Mildew (*Microsphaera alni*)

1. **Structure.** Observe the upper surface of leaves infected with the parasite and note
   a. The white mycelium covering the leaf surface with a whitish mass of hyphæ. Is this the plant body of the fungus? How is it anchored to the leaf and how nourished? What is the structure of the body of the plant?
2. **Reproduction by ascocarps, or fruits.** These are dark bodies scattered over the surface of the leaf.
   a. Distribution of the ascocarps. Outline a portion of a leaf surface, showing the distribution of the mycelium and the ascocarp fruits on a leaf.
   b. Structure of ascocarps and asci. Remove ascocarps to a slide in a drop of alcohol and glycerin by scraping them from a leaf with a needle. Avoid scraping off dirt and portions of the leaf. Note with low power
      (1) *The dark wall and appendages.* The structure of the wall can be ascertained by slight crushing. Note its cellular structure if it is not too dark. Note the shape and attachment of the appendages to the wall of the fruit. Draw a fruit body and one or two appendages.
      (2) *Asci and ascospores.* These are obtained by crushing ascocarps under a cover glass with a needle. How do asci and spores get out of the fruits in nature? When will spores be liberated and disseminated? How disseminated?
      (3) *Spores.* Note their shape and the number in each ascus.
3. **Drawings.** Draw a fruit body from which asci are being pressed out. Draw an ascus and spores.

SECTION VII. *BRYOPHYTA* (LIVERWORTS AND MOSSES)

A. HEPATICAE (LIVERWORTS)

GAMETOPHYTE

The following outline for laboratory work is based upon the relation of structure to function in liverworts. The outlines are made so general in their nature that any one of several species of thallose liverworts may be used. The term *thallus* applies to a plant body without true roots, stem, and leaves.

1. **Habitat.** From observations of living material and text figures and descriptions determine whether liverworts are typically mesophytic, hydrophytic, or xerophytic in habitat.
2. **Habit and growth.**
   a. The apical meristem of liverworts is located in the notches, or indentations, at the ends of the green lobes of the plant body, or thallus. With this knowledge determine the method of elongation and repeated forking (dichotomy) of the branches. How is the rosette form of *Ricciocarpus* and similar liverworts attained by this method of growth? How would new independent individuals arise from a rosette, or colony of branches? Is this a form of asexual or of vegetative reproduction?
   b. Sketch a liverwort with several lobes, or branches.
   c. Discuss briefly in your notes the method of growth and the formation of rosettes and of new individuals.

3. **Structure and function.**

a. Adaptations for absorption.

(1) Observe with a hand lens the ventral surface of liverworts which have been freed from soil. What structures do you find? Mount and study under a compound microscope. How do these structures (rhizoids) differ from true roots? What other structures do you find and how are they related to the plant body? Do these structures have any particular function?

(2) Sketch the lower surface of the liverwort, indicating the position of the structures seen. Label rhizoids and scalelike leaves. Draw more in detail one or more rhizoids.

b. Light relation and photosynthesis.

(1) Is the general form of the liverwort thallus adapted for photosynthesis? Be able to explain. Examine the dorsal (upper) surface of the thallus with a hand lens. Do you find anything corresponding to stomata and the green mesophyll areas of leaves of the higher plants? Thin surface sections should be examined if difficulty is experienced in determining the structure of the dorsal surface.

(2) Sketch accurately the structure of the dorsal surface of the thallus as it appears under the hand lens or low power.

(3) *Sections.* Study sections cut vertically through the plant body, using low powers of the compound microscope or a good dissecting microscope. Compare the structure of the dorsal portion of the liverwort with that of a green leaf. Are there air spaces and an internal atmosphere? What is the disposition of green chlorophyll cells?

Do you find stomata? What kind of tissue is below the green chlorenchyma? What is its function? Outline the section and detail a small portion of its cellular structure. Label correctly. Summarize the adaptations of the thallus of the liverwort for photosynthesis and absorption.

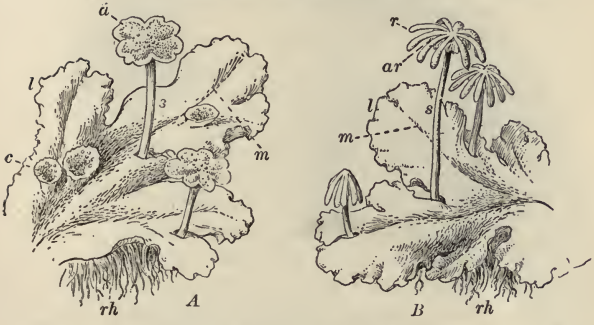

FIG. 22. A common liverwort (*Marchantia*)

A, antheridial plant; *B*, archegonial plant. *rh*, rhizoids, and *m*, midrib, of the leaflike flattened body *l*; *c*, capsules in which vegetative reproductive buds are formed; *s*, upright stalks (*a*, antheridial and *ar*, archegonial, the latter being distinguished by peculiar rays *r*). Slightly more than natural size. From Bergen and Caldwell's "Practical Botany"

c. Storage and conduction. Are there any such structural devices for storage of reserve foods and for conduction of water and foods in liverworts as we have found in the higher plants? Be able to explain.

4. **Reproduction.** If *Marchantia* is used for the following study, the peculiar reproductive branches (receptacles) will need to be explained by the teacher.

a. Distribution of sex organs.

(1) Study the distribution of sex organs on the dorsal surface of the thallus in *Ricciocarpus*, *Conocephalus*,

or similar liverworts, using a hand lens. Are the male and female organs aggregated or scattered over the surface? Are the plants monœcious

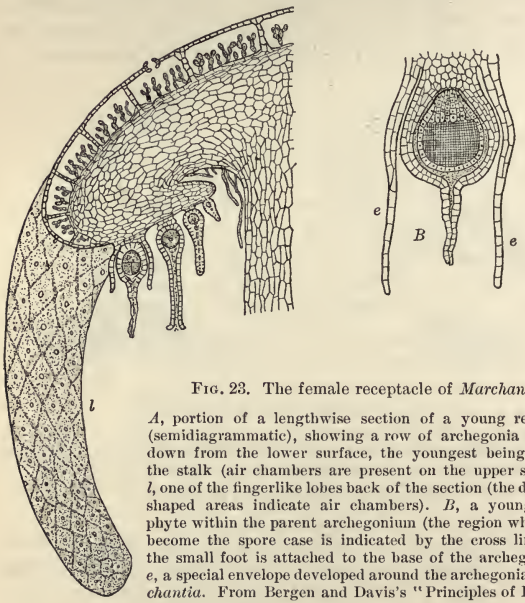

FIG. 23. The female receptacle of *Marchantia*

A, portion of a lengthwise section of a young receptacle (semidiagrammatic), showing a row of archegonia hanging down from the lower surface, the youngest being nearest the stalk (air chambers are present on the upper surface); *l*, one of the fingerlike lobes back of the section (the diamond-shaped areas indicate air chambers). *B*, a young sporophyte within the parent archegonium (the region which is to become the spore case is indicated by the cross lines, and the small foot is attached to the base of the archegonium); *e*, a special envelope developed around the archegonia of *Marchantia*. From Bergen and Davis's "Principles of Botany"

(with male and female organs in separate groups on the same thallus) or dicœcious (with male and female organs on separate plants? If the organs are separate, how is fertilization to take place?

(2) Sketch plants, showing the distribution of sex organs. Label.

b. Archegonia and antheridia (structure of sex organs). Study sections of plants cut so as to show the form and structure of the sex organs.

(1) Note in each organ an outer layer and a central column of cells. What is the cellular structure of these two groups of cells? the function of each? Are these cell groups alike in the female organ, or archegonium, and in the male organ, or antheridium? If sex organs of different ages are available, note the method of liberating sperms and exposing the eggs for fertilization.

(2) *Comparisons.* How do the archegonia and the antheridia of the liverwort differ from the gametangia (oögonia and antheridia) of algæ and fungi? Are archegonia and antheridia better adapted for securing the development of gametes and fertilization in amphibious plants like liverworts than the gametangia of algæ and fungi? Be able to explain.

(3) Write a brief summary of the structure and adaptations of the sex organs in liverworts. Indicate also the important distinctions between archegonia and antheridia and the gametangia of algæ and fungi.

(4) Draw diagrams illustrating the structure of each. Study the structure of the sex organs in the text and label parts of your figures accurately.

SPOROPHYTE AND LIFE HISTORY

1. **Sporophyte.** Study sporophytes of *Ricciocarpus* or other liverworts by dissection and in sections.

a. Structure. What kinds of tissues and cells are found in the sporophyte that you are examining? What is the apparent function of the tissues and cells

observed? Draw the sporophyte or the sporophyte and surrounding tissues if studied in section. Label the parts according to function.

b. Dissemination of spores. Are there any distinct devices for spore dissemination in the sporophyte that you are studying? How would the spores be liberated? What is the nature of the spore cell and how is it adapted for dissemination and for withstanding dessication, or drying, by wind and sun?

c. Comparisons. Is the sporophyte a new structure in plants studied thus far? What is its particular use, or function, in the life history of the amphibious liverworts? Would such a structure be equally useful in the life history of the fresh-water algæ?

2. **Life history.** Write a graphical life history of the liverwort that you are studying, similar to the life histories already written for *Spirogyra* and fungi. Explain in your notes the special adaptations of the gametophyte and the sporophyte to seasonal conditions and changes.

B. MUSCI (MOSSES)

GAMETOPHYTE

1. **Habitat.** What is the usual habitat of mosses? Are they for the most part mesophytes, hydrophytes, or xerophytes in habitat and structure? Do you know of exceptions to the general rule? Can you think of advantages to be derived from the clustered habit of growth of the mosses? Would this habit be of any advantage in securing food, moisture, and light, or in insuring fertilization of eggs by the motile sperms of mosses? Summarize your ideas of habitat in your notes.

2. **Habit.** Wash the earth from some moss plants and prepare them for study. Observe the parts of the plant body and compare them with those of higher seed plants.
   a. Plan of the plant body. Is the central axis divided into regular nodes and internodes? Are there lateral and terminal buds? Are the leaves cyclic or spiral in arrangement? Have the hairlike roots, or rhizoids, any definite points of origin on the stem? Do roots and leaves have any definite tropic response? Sketch a stem, using outline figures to indicate the relation of parts of the plant body of the moss.
   b. Study the microscopic structure of the leaves and rhizoids and indicate the cellular structure of these organs by accurate drawings.
3. **Reproduction.** Study plants which have antheridia and archegonia in the terminal buds. The males may be recognized as open disks, or clusters of antheridia, terminating the stem. The female plants have similar clusters of archegonia borne in closed buds.
   a. Male disks and antheridia. Cut off the male head and dissect it out in a drop of water on a slide.
      (1) What is the shape of the moss antheridium? its structure? Is it composed of different cell layers? How do these layers differ in structure? What function do you consider that each cell group, or layer, has in the development and liberation of sperms? Do you find other cell structures among the antheridia? Sterile cell chains, called paraphyses, exist among the antheridia of most mosses, which probably protect the developing antheridia.
      (2) Draw antheridia and paraphyses. Label the parts of the antheridium according to position and function.

(3) If sections of antheridia are available, study in some detail the structure of the outer protective layers of the antheridium and the inner sperm mother cells. Make an accurate drawing of a section of an antheridium.

b. Female heads. Observe the difference in appearance of male and female heads in mosses. Dissect out female heads, as for the males above, or study sections cut through female heads of a moss.

(1) *Sections.* If sections are studied, note the origin of the archegonia from the apical meristem of the moss stem. What is the form and structure of the archegonium? Is there an outer protective layer and a central column of cells as in the antheridium? Find the egg in the basal swollen part (venter) of the archegonium. Detail one or more archegonia and cells of the meristem from which they arise.

(2) *Dissections.* If slides are not available, archegonia may be dissected out of female heads as for antheridia above. Draw archegonia if found by this method, indicating the structure of the outer protective layer and of the central column of cells. See the account of the structure of the archegonium under *Ricciocarpus* and the moss in the text.

(3) *Comparisons.* Compare the archegonium of the moss and the oögonium (gametangium) of algæ. How do they differ? In what respects is the archegonium better adapted for insuring fertilization in land plants than the simple gametangia of the algæ?

SPOROPHYTE

1. **Mature sporophyte.** Select a moss plant bearing a mature sporophyte and study the relation of the gametophyte and sporophyte.

   a. Cut away the gametophyte on one side so as to expose the base of the sporophyte. Is the sporophyte a parasite on the gametophyte?

   b. Parts of the sporophyte.

   (1) Study sporophytes carefully with the naked eye and with a hand lens. Is the enlarged part (capsule) differentiated into parts? Note its connection with the gametophyte. Draw the sporophyte and label its parts after reading the text description of the sporophyte.

   (2) *Operculum, peristome, and spores.* With dissecting needles remove the operculum and expose the peristome. What is its structure in the moss that you are studying? How many teeth are there in the peristome? Breathe on the peristome teeth and observe quickly under low power. What is the nature of the movement of the teeth? What is the function of this movement in the scattering of spores? Draw a portion of the peristome as seen under low and high powers.

   (3) *Spores.* Remove spores from a capsule with needles and note their size, form, and structure. Is a spore a cell? Is it a reproductive cell? How is it adapted to dissemination and to resistance to the effects of sun and drought? How do these spores differ from spores of the algæ?

   (4) *Spore germination.* What do moss spores produce when they germinate? See text and laboratory

material if available. How does the leafy moss gametophyte arise?

2. **Embryo and young sporophyte.** Study stages in the development of the sporophyte. What relation does the old archegonium wall sustain to the growing sporophyte? to the mature capsule? Draw stages in the development of the sporophyte. Label sporophyte and old archegonium after reading the text discussion of these structures.

LIFE HISTORY AND SEASONAL HISTORY

1. What are the two alternating generations of the moss, and how do they differ from similar stages in *Ricciocarpus*? See the life history of *Ricciocarpus* in the text.
2. Write a graphical life history of the moss plant, using outline figures. Indicate in the history the protonema and gametophyte, and stages in the development of the sporophyte.
3. **Seasonal history and alternation of generations.**
   a. Are the mosses annuals, biennials, or perennials in habit? How do they pass the winter? Determine the main nutritive and reproductive seasonal activities of common mosses. Contrast the seasonal history of mosses with that of higher plants outlined in an earlier part of the text. Are the alternating generations related to seasonal life? If so, how? Would this seasonal relation be different in different mosses? Investigate this point for yourself as far as possible by studies of mosses out of doors and in textbooks.
   b. Write a brief account of your findings on the above points and hand in with your drawings.

SECTION VIII. *PTERIDOPHYTA* (FERNS, EQUISETA, AND LYCOPODS)

The *Pteridophyta*, as indicated in the text, are the plants from which the higher plants had their origin in geologic periods earlier than the present era. Their organization and life history are therefore of especial interest in interpreting the structure, ecology, and life history of the higher plants. In order to make clear the contrasts and similarities between the *Filicales*, or true ferns, and the higher seed plants, the following laboratory directions are written, from the same standpoint and with similar headings and references as the directions on the higher herbaceous and woody plants of Part I. Constant reference is also made to the earlier work of the student, and to the text dealing with the organization and adaptations of higher plants to the environment.

A. FILICALES

SPOROPHYTE

Select for study one or more species of common wild and cultivated ferns which show both mature and young, growing leaves. Wash the earth carefully from stem and roots of at least one specimen and study as follows:

1. **Plan of the plant body.** Compare the general plan of the plant body of a fern with that of herbaceous and woody plants studied earlier in the course, and with such seed plants as may be available for comparison.
   a. Is the central axis, or stem, divided into nodes and internodes, with regular points of origin for leaves

and roots? Are there lateral and terminal buds? How does the terminal bud of ferns differ from that of higher plants? Can you think of reasons for the differences observed? Are there lateral branches, and if so, have they a definite arrangement? Observe the ramenta, or brown scales, characteristic of ferns on the stem, leaf bases, and young leaves. What is the probable function of these ramenta as the terminal bud unfolds in the spring?

2. **Leaves.**

   a. Mature leaves. Contrast the mature leaves of ferns with those of higher plants in size, form, texture, and venation. What are the distinctive characteristics of fern leaves accessible to you, and of fern leaves known to you, as compared with those of higher seed plants? Study the mode of venation and the termination of the veins, comparing ferns and some common seed plants in this respect.

   b. Young leaves. Study the growth and form of young leaves of the terminal bud. What are the distinctive characters of young fern leaves as regards form and method of growth?

3. **Roots.** Study the mode of branching of roots. Is there any distinctive feature which characterizes ferns in this respect as compared with higher plants? Determine also the origin and distribution of roots on the stem.

4. **Adjustments to the environment by tropisms** (see the text, Part I, and earlier laboratory work on tropisms). Determine the tropisms of the stem, roots, and leaves of ferns and apply proper terms to indicate the nature of stimulus and response, — for example, *protropic*, *apotropic*, and *diatropic*.

5. **Distinctive characteristics.** Summarize in your notes under the above headings (namely, body plan, leaves, roots, and the tropisms of the central axis and lateral organs) the distinctive characteristics of ferns as compared with higher plants.

6. **Drawings.**
   a. Make an accurate drawing of the fern examined.
   b. Bring out as largely as possible, in the main drawing and, where necessary, by detailed drawings of certain organs (for example, leaves), the distinctive characteristics of ferns named above under 5.
   c. Draw an outline figure, indicating the positions assumed by the organs in a cultivated or wild fern. Indicate stimuli and the nature of the response of the plant organs by use of the proper terms, as in the earlier studies of seed plants in Part I.

7. **Habitat, habit, and environment.**
   a. Habitat. What is the common habitat of ferns in your region? Are they typically mesophytic, xerophytic, or hydrophytic? Do you know of exceptions to the general rule?
   b. Environment. Compare the environment of common wild ferns growing on the forest floor with ferns growing in homes, and with common seed plants growing in the open. How would these three habitats compare as regards heat, light, soil water, food elements in the soil, and the relative humidity of the air? Answer these questions in a paragraph in your notes.
   c. Habit. How is the habit of wild ferns especially adapted to the above environment as regards the form, size, and texture of the leaves? Do cultivated ferns manifest a different structure?

d. Seasonal life. Are ferns annuals, biennials, or perennials in habit? How do they pass the winter? What is the function of the rhizome in the winter season? Be able to indicate the seasonal activities of the fern in a manner similar to that outlined for the bean, clover, and apple in Part I of the text.

e. Summarize the principal seasonal activities of the fern plant during summer, spring, and winter, indicating the main plant organs concerned.

8. **Anatomy of maidenhair fern (*Adiantum*).** Examine with a hand lens and low powers of the microscope transverse sections of a fern stem, or rhizome, like that of *Adiantum*, with a tubular vascular cylinder of phloëm and xylem.

a. Gross arrangement of tissues. Do you find the same general tissue layers in the fern rhizome as in the herbaceous stems studied earlier in the course? (Consult figures and text discussion on herbaceous stems.) Are there the same general subdivisions of the cortex into stereome and storage tissues, and of the vascular ring into phloëm, cambium, and xylem as in herbaceous stems? Note the relative width of the cortex, vascular cylinder, and pith in the fern and in herbaceous and woody stems.

b. Leaf traces and leaf gaps. Study sections of a fern rhizome cut through the point of exit of a leaf.

(1) Is the vascular cylinder broken, forming a break, or gap, with a small leaf bundle (the leaf trace) in section opposite the gap? Consult the text descriptions and fix clearly in mind the nature and relations of leaf trace, leaf gap, and the vascular cylinder as a whole. See also the text figures on the anatomy of *Adiantum*.

(2) *Root traces.* The root bundles which enter the lateral roots may sometimes be found leaving the vascular cylinder. Do they leave a gap as in the leaf bundle?

(3) *Drawing.* Outline your entire section, indicating the main tissue layers and their subdivisions and the relations of leaf trace, leaf gap, and central cylinder. How does *Adiantum* differ from an herbaceous plant like *Salvia* in its gross anatomy? Consult the text discussion of *Salvia* in Part I.

e. Minute structure of the tissues.

(1) *Epidermis, cortex, and pith.* Draw in detail a few characteristic cells of each of the above layers and their main subdivisions, to show the distinctive cell characteristics of each tissue. Label the parts of the cells. What is the function of each cell type in the rhizome, and how is its structure adapted to its function?

(2) *Vascular cylinder.* Study the following tissues of the vascular ring and leaf trace critically with low power:

(*a*) *Xylem.* Characterized by large water-carrying cells resembling ducts in higher plants. These xylem cells, or tracheids, stain red where sections are stained with safranin (the dye commonly used in staining xylem). Are there rays or other living tissues in the xylem of ferns, as in that of higher seed plants previously studied?

(*b*) *Phloëm.* Surrounding the xylem. The sieve tubes are the large cells seen in the phloëm flanking the xylem on either side.

(*c*) *Cambium.* Is there any evidence of a cambium composed of regular cells as in higher plants?

(*d*) *Endodermis.* A dark-brown layer surrounding the phloëm, beneath which is a single cell layer containing starch, called the pericycle.

(*e*) Does the leaf trace have the same structure as the main vascular cylinder?

(3) *Drawing.* Make a cellular drawing of a small portion of the main vascular cylinder, or of the leaf trace to show the structure of the tissue elements. Label correctly.

(4) *Summary.* Summarize the distinctive features of the tissue arrangements in the fern as compared with that of herbaceous dicotyledons. See the summary of the anatomy of herbaceous stems in Part I of the text.

9. **Anatomy of eagle fern (*Pteris aquilina*).**

a. Gross anatomy. Study transverse sections of the eagle fern, as indicated above for *Adiantum*, using a hand lens first and then low powers of the microscope. Compare the main tissue layers with those of the maidenhair fern.

(1) *Epidermis and cortex.* Are both epidermis and cortex present, and do they have the same cell characteristics as in the maidenhair fern? Is there an exoskeleton in *Pteris?*

(2) *Vascular ring.* Study the vascular system carefully with a hand lens and low power. Is there anything corresponding to the single vascular ring of *Adiantum*? What kinds of tissue masses occupy the pith region? Do you find central skeletal, or strengthening, masses and vascular strands? See text discussion of the eagle fern (*Pteris aquilina*).

(3) *Drawings.* Construct an outline figure (no cells) of the cross section of the stem of *Pteris.* Label the parts accurately. Discuss briefly the distinctive features of the anatomy of the eagle fern as compared with that of *Adiantum.*

b. **Minute anatomy.**

(1) *Transverse sections.* Work out and draw the cellular structure of one vascular strand of the rhizome in *Pteris* and label accurately. Draw also a few cells of the epidermal, of the skeletal, and of the storage tissues.

(2) *Long sections.*

(*a*) *Skeletal tissue.* Work out and draw a few cells of the strengthening, or skeletal, tissue as seen in long section. Are these cells living? What are their most distinctive structural characteristics? Explain in your notes.

(*b*) *Vascular tissues.* Study the vascular tissues in long section. Find the sieve tubes of the phloëm and water-conducting cells, or tracheids, of the xylem. Determine the shape, size, and wall markings of each type of cell element.

(*c*) *Sieve tubes.* Find in the sections the abundant sieve plates. Consult text figures. Be able to discuss the structure and function of the sieve plates. Draw accurately one or more sieve tubes and the adjoining cells.

(*d*) *Tracheids.* Study the form, cell contents, and cell-wall thickening of the tracheids. How does the tracheid differ from the duct, or vessel, of the higher plants? Is it as efficient in water conduction as the vessels are?

Determine with care the thick and thin areas of the wall. Which area constitutes the greater portion of the entire wall of the tracheid? What is the function of each in the work of the tracheid and the stem?

(*e*) *Summary.* Draw and discuss briefly the structure and functions of the tracheids as compared with the ducts of the higher plants.

10. **Asexual reproduction.**

a. The sorus. Observe the lower (abaxial) surface of fern leaves for clusters of fern sporangia, or sori.

(1) What is the position of the sori with reference to the veins? Can you think of a reason for this position? Are the sori numerous or infrequent on the leaves that you are examining? What advantages has the fern sporophyte over the moss sporophyte in the production of spores? See text discussion for the number of fern spores produced by a single sporophyte annually.

(2) *Structure of the sorus.* With hand lens and low power of the microscope determine the structure of the sorus. Has it a covering? Do sori of different ages have a different color and appearance? To what is this difference in color due? Where there is a membranous covering (indusium), note its form in young sori, and the method by which the brown sporangia became exposed to the air in older sori. If different species of ferns are available, observe sori and indusia of different shapes and forms. Draw a single pinnule of a fern to show the form, structure, and distribution of the sori. Compare the indusia in your specimens with those shown in the text (Figs. 168 and 176).

b. Sporangia and spores.

(1) Dissect out sporangia into a drop of water on a slide. Mount and study the cellular structure of the sporangium carefully. Are the cells all alike in structure and in function? To demonstrate this point remove sporangia to a dry slide. Breathe on them gently and observe quickly under low power. Result? Consult the text discussion of spore dissemination.

(2) Draw accurate diagrams of a closed and an open sporangium as you observe them in your own preparations. Be prepared to explain the peculiar structure and mechanism of the annulus.

SUPPLEMENTARY STUDIES

1. **Sporogenesis.** If slides are available, the essential stages in sporogenesis, or spore formation, may be worked out, illustrating the archesporium and tapetum, the sporogenous and spore mother-cell stages, and the formation of tetrads and spores.

2. **Analysis and classification.** Each student should learn to use the analytical key and analyze a few species of common ferns. Record your analyses as follows:

a. Family _____.
b. Genus _____.
c. Species: scientific name, _____; common name, _____ _____.

GAMETOPHYTE

After examining growing fern gametophytes, determine and record the following points concerning the habitat and nature of the gamete-bearing plant, or gametophyte generation, of the ferns:

1. **Habitat.** What is the natural habitat of these little plants in nature? Does your observation indicate that fern

gametophytes are abundant in their natural habitat? Why not, since ferns produce abundant spores?

2. **Habit.** What group of plants already studied have gametophytes most similar to those of ferns? Is this group closely related to ferns? What is the most striking difference between the ferns and the *Hepaticae* as regards their gametophyte and sporophyte plants?
3. **Structure.** Wash the soil from the underside of mature gamete plants. Determine the structure of the plant body and the nature of the absorbing organs.
4. **Sex organs.**
   a. Study the position of the archegonia and antheridia on the ventral side of the gametophyte. Observe in models and in the text the structure of these organs. Are they essentially the same as those in the *Bryophyta*? How would fertilization be effected? Is the position of these sex organs favorable for insuring fertilization? Be able to explain.
   b. If sections are available, the student should study sections cut through the gametophyte and the sex organs for a more exact knowledge of the structure of the archegonia and antheridia.
   c. Development of the gametophyte. Study germinating spores which show early stages in the formation of the gametophyte. Draw and label stages observed.

THE EMBRYO AND THE LIFE HISTORY

1. **Embryo.** Study young sporophytes growing from gametophytes. What are the parts of the spore plant? How are they attached to the gamete plant? What relation does this young spore plant bear to the adult sporophyte? Consult the text figures on this point.

2. **Life history.**
   a. Construct a graphical life history of the fern similar to that of *Ricciocarpus.*
   b. Contrast briefly in your notes the alternating generations of the fern and the bryophyte.

B. EQUISETALES (HORSETAILS)

SPOROPHYTE

Compare the main subdivisions of the plant body of some species of *Equisetum* with that of the true ferns as regards both form and function.

1. **The plant body and its plan.**
   a. Main subdivisions. Has the *Equisetum* plant the same divisions into horizontal rhizome, aërial green leaves, and roots as the true ferns? What organs perform the functions of photosynthesis, absorption, conduction, and storage? What portions would carry the plant over winter or extreme drouth? How does *Equisetum* differ from ferns as regards the above points?
   b. Vegetative parts. Is the main stem segmented into regular nodes and internodes? Is the leaf-and-branch arrangement cyclic or spiral? Determine the origin of lateral buds and branches with reference to the leaves. Is it the same as in higher plants? Compare the aërial and underground stem and lateral branches in these respects. Are they all constructed on the same plan? Note any variations that may occur. Observe the origin and nature of the roots.
   c. Strobili, or reproductive cones. Observe these structures and their position on the plant. Are their parts (as seen externally) arranged on the same plan as

the leaves on the main axis, thus following the general body plan? Is the strobilus placed in the right position on the shoot for spore dissemination?

2. **Adjustments to the environment.** Are there the same responses to environmental forces by tropisms in *Equisetum* as in ferns? Be able to explain the relation between the responses of the various organs and the functions which they perform.
3. **Drawings.** Make an accurate drawing of the *Equisetum* plant studied, to indicate the subdivisions and plan of the plant body. Indicate by proper terms the responses and adjustments of the various organs to environmental forces.
4. **Analysis.** Analyse one or more species of *Equisetum* and record analyses under family, genus, and species, as in ferns.
5. **Habitat and habit.**
   a. What is the usual habitat of the equiseta? Are there variations in habitat? Determine these points by field studies and by reference to texts and analytical keys. Does the habitat of species growing in ponds or lakes correspond to the form and structure of these species? How can you explain the evident discrepancy between habitat and habit in these cases?
6. **Seasonal history.** Are equiseta annuals, biennials, or perennials? herbaceous or woody plants? In what form do they pass the winter? How do they differ from ferns in these respects?
7. **Summary.**
   a. Summarize the distinctive characteristics of equiseta which differentiate them from true ferns.
   b. Explain the apparent discrepancy between habitat and habit in species growing in water.

SUPPLEMENTARY STUDY

Equisetum arvense

Sporophyte

1. **Dimorphic character of the aërial stems.**
   a. Compare aërial vegetative and reproductive shoots of *Equisetum arvense* as to body plan, lateral organs, and color. What is the apparent advantage of this division of labor in aërial stems? Do the reproductive and the vegetative shoots grow at the same time of the year? Which has the longer life?
   b. Construct a diagram to show the relations of the underground and the dimorphic aërial portions of *Equisetum arvense.* Label parts correctly.
2. **Structure and reproduction.**
   a. Structure. Cut thin sections across the stems of *Equisetum arvense.* Mount and study with a low power.
      (1) Locate the main tissue layers: namely, epidermal, skeletal (or supporting), vascular (or conducting), and storage tissues. How does the general arrangement of tissues differ from that found in the fern? Can you relate the position of the various tissues to their use, or function, in the plant body, — for example, the skeletal and the green tissue? Why are both of these tissues placed on the outside of the stem? Why is the vascular tissue so small in amount? What are the advantages of the large intercellular spaces?
      (2) Make an outline drawing (no cells) of your section illustrating the position of the various tissues.
      (3) Summarize the adaptive features of the structure of the stem.
   b. Asexual reproduction.
      (1) Compare the arrangement of the parts of the strobilus of *Equisetum arvense* with that of the species examined above as to plan and arrangement of parts.

(2) *Bisect a strobilus.* What are the parts of a strobilus thus exposed? Is the strobilus a modified shoot? Are there nodes, internodes, and lateral members, as in the main central axis?

(3) *Sporangiophores and sporangia.* The sporangiophores are the shield-shaped lateral organs of the strobilus which bear the sporangia. They are not true sporophylls, or modified leaves. How many sporangia are there on a single sporangiophore? How are they arranged? What is the shape of a sporangium? Dissect sporangia out on a slide to determine this point. Can you determine the mode of opening in rather mature sporangia? Draw sporangia to show the line of dehiscence.

(4) *Spores and elaters.* Dissect spores out on a slide (let them dry if preserved material is used). Breathe on them gently. Result? Study the structure of the spores. Draw them. See the text for a description of spore structure. Label your drawing.

3. **Life history and relationships.** Study the life history of *Equisetum* in the text.

a. Why are these plants classified with the ferns under the common group *Pteridophyta*?

b. In what respects are the ferns and equiseta alike in their life history? Summarize your conclusions respecting *a* and *b* in your notes.

C. LYCOPODIALES (CLUB MOSSES)—*LYCOPODIUM*

SPOROPHYTE

1. **The plan of the plant body.** Compare with that of true ferns and equiseta. Are there characters concerned with the central axis or the lateral members (leaves, roots, and branches) which distinguish lycopods from the other *Pteridophyta* already studied?

2. **Asexual reproduction.**
   a. Observe the strobili of a lycopod which is bearing spores. What is the position of the strobilus on the stem? Are its parts of the same general nature and arrangement as those of the main axis?
   b. Structure of strobilus, sporangia, and spores. Determine these points by dissecting the leaves, or sporophylls, from strobili. How is the sporangium related to the scalelike leaves (sporophylls) which bear them? How and where do the sporangia open (dehisce) to shed the spores? Are the spores numerous and all of one kind, namely, homosporous?
   c. Draw a single sporophyll with its sporangium.
3. **Analysis.** Analyze two or more species of lycopods and record your analyses as for ferns and equiseta.
4. **Distinctive characters.** Summarize the characters which seem to you to distinguish lycopods from other *Pteridophyta* studied.

SELAGINELLA

SPOROPHYTE

Study one or more species of *Selaginella* with reference to the following more important and distinctive features of these plants:

1. **Body plan and adjustment of organs to the environment.**
   a. Leaves.
      (1) Note their arrangement and adjustment to light. If erect and creeping species are available, compare them in these respects.
      (2) Note the ligule, a small outgrowth on the adaxial side near the stem. This is an ancestral character which existed in the lycopods of early geologic periods.

b. Rhizophores and roots. The rhizophores are naked, stem-like organs which bear the roots at the tip, where the rhizophores come in contact with the soil. What

FIG. 24. *Selaginella martensii*

A, branch bearing cones and showing the leaf arrangements; *B*, inner face of a megasporophyll, showing the large megasporangium containing a group of four megaspores (tetrad); *C*, two views of megaspores; *D*, inner face of microsporophyll, showing microsporangium; *E*, microspores; *F*, diagram of a longitudinal section of cone, illustrating position of microsporophylls and megasporophylls and their microsporangia and megasporangia. From Bergen and Davis's "Principles of Botany"

would be the function of these rhizophores in the natural habitat of *Selaginella*? The rhizophore is also an ancient organ which occurred in the early relatives of *Selaginella*.

c. Draw a portion of a *Selaginella* plant to illustrate the above points.

2. **Asexual reproduction.**

a. Strobili. Do the species of *Selaginella* that you are examining bear distinct strobili? What is the nature of the sporophylls? Do they resemble ordinary leaves in form and color? Why are they called sporophylls?

b. Sporangia and spores.

(1) Remove sporophylls from different parts of the strobilus and examine the sporangia. Are the sporangia all alike in appearance and in the number of spores which they bear? Dissect spores from several sporangia to determine this point. What do you find? Have we studied any plants before which bore two kinds of spores? Do any particular portions of the strobilus bear a particular kind of sporangium and spore?

(2) Draw the two kinds of sporangia and sporophylls found in the strobili that you are examining. Draw the two kinds of spores. Read the text on asexual reproduction of *Selaginella* and label your figures correctly.

(3) *Study of sections.* If sections of strobili of *Selaginella* are available, study the relations of the microsporangia and megasporangia to the main axis of the strobilus and to the sporophylls. Observe the structure of the sporangia and spores. Draw and label your figure.

3. **Life history.** Study the text figures and discussions concerning the gametophytes, sex organs, and life history of *Selaginella.*

4. **Distinctive characteristics.** Summarize the new and distinctive characters of *Selaginella.*

SECTION IX. GYMNOSPERMS

A. CYCADALES (CYCADS)

SPOROPHYTE

1. **Habitat and relationships.**
   a. Consult the text and assigned readings concerning the habitat, classification, and relationships of the *Cycadales.* What is the natural habitat of the cycads in the United States? Were they ever more abundant and important as a part of the world's vegetation than they are at the present time? What position in classification do they occupy among living plants? What ancestral relationships have they which make them important to study in a course in plant evolution?
   b. Summarize answers to the above questions in your notes.
2. **Habit and body plan.**
   a. What is the body plan of cycads? See the arrangement of leaf bases and green leaves on the stem. Do you know of ferns or seed plants which the cycads resemble in general habit? Are the cycads closely related to such plants?
   b. Leaves. Study young and mature leaves of cycads. In what respects do cycad leaves resemble those of ferns? If leaves are unfolding, notice the method of unfolding of the entire leaf and of the pinnules. If possible, note the venation of leaves of *Cycas* and *Zamia.* Are the resemblances of cycad leaves to

those of ferns a matter of chance or one of blood relationship?

c. Roots. Are the roots of cycads distinctive? If so, in what respects?

3. **Asexual reproduction.** Study living or preserved material or museum specimens.

a. Strobili. Determine the position of strobili on the main axis, the distribution of male and female strobili on the same or on different plants, and the general nature of the strobili.

(1) Are the strobili terminal or lateral in origin? Are the plants monœcious or diœcious as regards the distribution of strobili?

(2) Are the parts of the strobilus arranged on the same plan as those of the main plant body? To what parts of the plant body do the main parts of the strobilus correspond? Are there sporophylls and a central axis as in the lycopods and *Selaginella*? Are the sporophylls cyclic or spiral?

4. **Sporophylls and sporangia.**

a. Microsporophylls, sporangia, and spores.

(1) *Sporophylls.* Note the form and relation of the sporophylls. Compare (by means of specimens or figures) the sporophylls of different kinds of *Cycadales.* Are any of them leaflike? To what do these sporophylls correspond in ferns? in *Selaginella* and lycopods?

(2) *Microsporangia.* Are the microsporangia abaxial or adaxial on the sporophyll? Has their position any relation to spore-shedding? Is there any definite arrangement into sori?

(3) *Spores.* Search for sporangia shedding spores. Is there a definite line of dehiscence? Study spores

and compare them with those of ferns and *Selaginella*. Do cycad spores differ in structure or in function from those of *Pteridophyta*?

(4) *Drawings.* Draw the ventral (abaxial) view of a microsporophyll and its sporangia. Label. Draw two or three microspores.

b. Megasporophylls and sporangia.

(1) Remove entire sporophylls with their megasporangia, or ovules, from the female strobili. Note young or undeveloped megasporangia if found. Are these megasporangia, or ovules, similar to the ovules of the mandrake and the bean studied earlier in the text? Consult these earlier figures and text descriptions. If they are the same, are all ovules and seeds megasporangia?

(2) *Gross structure of the megasporangium.* Bisect the megasporangia of *Zamia* and study their structure as shown on the cut surface. Compare the *Zamia* megasporangium with that of the mandrake. Do you find integuments, micropyle, and funiculus in the megasporangium of *Zamia*? What fills the center of the sporangium? Do you find structures looking like archegonia, or eggs? Use hand lens and examine your specimen carefully.

c. Conclusions. What conclusions do you draw as to the nature of the megasporangium and its contents? Does it contain spores or structures belonging to a gametophyte generation? Does the sporangium ever open (dehisce) as in the microsporangia? State in summary form your conclusions as to relation of the megasporangia of *Zamia* to ovules of the mandrake, locust, and bean studied in Part I, and to megasporangia in the heterosporous *Selaginella*.

GAMETOPHYTE

Study text figures and descriptions of the megasporangium of *Zamia*. With the aid of such descriptions study your specimen with a hand lens and determine the relation of the following structures:

1. **The integument layers and the micropyle.** How do the layers of the integument differ? Is the micropyle of appreciable width?
2. **The pollen chamber and the remnant of the sporangium.** Do you find these structures in your specimen? How are they related to the gametophyte and the archegonial chamber?
3. **The gametophyte.**
   a. Is the gametophyte of *Zamia* as large as that of the fern? Has it the same functions? What was the source of its food supply? How was this in the fern? in *Selaginella*? Test the gametophyte with iodine. Does it contain reserve starch?
   b. Archegonia. How many archegonia are there on a single gametophyte of *Zamia*? How do they compare in structure with the archegonia of *Selaginella*, ferns, and mosses? Have any structures common to the earlier archegonia been lost? Note the archegonial chamber. What is its special function at the time of fertilization? Draw the upper third of the megasporangium and gametophyte to bring out the above structures. Label.
4. **Pollination and fertilization.** How is pollination effected in *Zamia*? Is self-pollination or cross-pollination the rule? How does the pollen grain reach the pollen chamber? What is the function of the pollen tube? How is fertilization effected in *Cycadales*? In what

respects is the process in cycads intermediate between that in ferns and that in the mandrake.

5. **Structure of the seed.** Study the structures of the seed in *Zamia* from specimens or from figures. Compare its structure with that of the mandrake and the pea. What sporophytic and gametophytic structures are comprised in the seed of *Zamia*? If specimens are available, draw a sectional view of the cycad seed to show the parts of the embryo and the remaining structures of the seed.
6. **Seed germination.** The method of seed germination in cycads is well illustrated by the germination of the acorns, or seeds, of the oak. The important things to note are
   a. The structure of the seed and embyro.
   b. The exit of the embyro from the hard seed coat.
   c. The function of the cotyledons and the exit of the plumule.
   d. The final adjustment of the young plantlet in the soil and air.

   If the acorn is used, make appropriate drawings to illustrate stages *a–d.*
7. **Life history.** Study the text diagrams in the graphical life history of *Zamia.* Be able to label and explain each stage of the life history illustrated in the diagram.
8. **Summary.** Summarize briefly the following points relating to the structure and reproduction of *Zamia* and the *Cycadales.*
   a. Summarize the fernlike characteristics of *Cycadales* which indicate their pteridophyte ancestry.
   b. Summarize their new gymnosperm characters.
   c. Give briefly the characteristics in which *Cycadales* are intermediate between *Pteridophyta* and the higher seed plants.

B. CONIFERALES (CONE-BEARERS). SPRUCE AND PINE

SPOROPHYTE

1. **Habitat** (Field study).
   a. What is the nature of the habitat of the spruces and pines of your region as regards soil, drainage, and climate? Do they grow best on lowlands or on well-drained slopes and uplands? What is the distribution of spruces and pines in the United States? What is their natural habitat as regards soil and climate? Are they mesophytic or xerophytic in general habit? How do you explain the apparent discrepancy between habitat and habit in these trees? Consult manuals and assigned readings on the above points.
   b. Summarize the above points in your notes under habitat, including geographical distribution and habit.
2. **Habit.**
   a. Form and body plan of the spruce and pine trees. Review the text discussion in Part I on the body plan and mode of growth of the spruce and pine trees. Be able to account for the erect conical form, the excurrent trunk, and the false whorls of branches of spruces and pines. Why is the trunk excurrent? What determines the conelike form of the entire tree? How do the false whorls arise? Is the entire leafage well exposed to light?
   b. Summarize the above points under Habit in terms of body plan, methods of growth of buds and branches, and tropistic responses of leaves and branches.

For a general discussion of the habitat, distribution, and commercial importance of the spruces and pines the student should consult the text and figures under Gymnosperms in Part III of text. See also the general map of forest areas (Fig. 223).

ANATOMY OF THE SPRUCE STEM

Transverse Sections

Cut thin transverse sections from living spruce twigs about one eighth of an inch in diameter. Mount some sections in alcohol and some in iodine solution. Observe the latter sections for starch storage, wood rays, pith, etc.

1. **The main tissue layers of the spruce.**

a. Compare the tissue layers of the spruce with those of the lilac and fern. Which stem does the spruce most nearly resemble in structure? Does the spruce possess both a cork cambium and the cambium which forms phloëm and xylem? Note carefully the relations of corky bark, green cortex, phloëm, cambium, xylem, and pith.

b. Leaf gaps and traces. Observe the shape of the pith. Do you find lobes of the pith (leaf gaps) extending into the xylem? If so, note their extent and the nature of the xylem ring opposite them. Leaf traces, looking like wide wood rays, often appear opposite these pith lobes or leaf gaps in the spruce. Consult the text figures.

c. Observe sections stained with iodine for starch-storage areas. Where is starch stored in the spruce?

d. Make an accurate drawing of your section in outline (no cells), indicating the main tissue areas and their limits. Include wood rays, annual rings, leaf gaps, and leaf traces. Study the text and label your drawing accurately.

e. Summary. Write an accurate and concise summary of the structure of the spruce stem in the form indicated for herbaceous dicotyledons and for the fern. Indicate

in the summary the particulars in which the spruce stem resembles that of the fern, and the significance of this resemblance. Consult the text on the structure of the spruce stem.

2. **Structure of the tissues** (prepared slides). Observe with low and high powers of the microscope the tissue layers and tissue elements in stained preparations of spruce stems.

   a. The cork bark. Of what kinds of tissue is it composed? Is there an apparent tendency to form separating scales? Are the cells of the cork bark living or lifeless? The cork cambium forms an inner layer of rectangular living cells on the inner side of the cork layers in the spruce.

   b. Cortex. Observe the character of its cells and the structure of the large resin canals with a lining layer of small resin secreting cells.

   c. Phloëm and cambium. Can you differentiate the phloëm and cambium layers? Does the phloëm show annual growth layers corresponding to those of the xylem? What marks the outer boundary of each annual layer of phloëm (this outer limit of the phloëm can be determined by the outer limit of the wood rays)?

   d. Xylem.

   (1) *Annual rings, composed of spring and summer wood.* Compare these with similar structures of woody dicotyledons. How do the tissue elements of the spring and summer wood differ in the spruce from similar structures in lilac and alder? Which kind of wood is better adapted for rapid water conduction? Is the wood structure adapted to the leaf structure and transpiration requirements in the spruce?

(2) *Storage tissues of the xylem.* Is the spruce as well provided with storage tissues as the above-mentioned stems? How does it compare with the storage system of the fern stem? Is the spruce intermediate in this respect between the alder and the fern? Be able to explain.

(3) *Drawings.* Outline a sector of a transverse section of the spruce stem. Detail in this sector the cork layer, a small portion of the xylem at the junction of two annual rings, a leaf gap, and a leaf trace.

Long Sections

Study thin sections cut from spruce or pine to determine the structure of the water-carrying tracheids and of the wood rays. Mount in alcohol if freshly prepared material is used.

1. **Tracheids.** What is the nature of the conducting elements, or tracheids, making up the wood of pine or spruce? Are they single cells? What is their shape? What are their surface markings? How do they differ from the vessels, or tracheæ, of the higher plants studied earlier in the course? Compare the ducts of the lilac and alder with the tracheids in your slide. Do the wall markings of tracheids differ from those of ducts? Study the bordered pits on the walls of the tracheids, consulting the text concerning their structure. On which walls of the tracheids are the bordered pits, the tangential walls or the radial walls?
2. **Wood rays.** If rays are seen in radial sections, note the differentiation of their cells into living starch-bearing cells and dead water-conducting tracheids.
3. **Drawings.** Draw a small portion of your section accurately to show the structure of tracheids and wood rays.

ASEXUAL REPRODUCTION

1. **Ovulate strobili of the spruce.** Study surface views of mature dry strobili of the spruce and median long sections of preserved strobili.
   a. Gross parts.
      (1) Are the parts of the spruce strobilus the same as those of strobili in lycopods and cycads? Are there sporophylls? a central axis? ovules or megasporangia? Is the strobilus cyclic or spiral in plan? Study both surface and sectional views of the strobilus to determine the above points.
      (2) *Seeds.* Do you find seeds or ripened megasporangia in the mature strobili? How are they adapted to dissemination?
      (3) *Drawings.* Draw surface and sectional views of portions of the strobilus about one inch in length. Draw the median section very accurately. Label the parts in terms of sporophylls and sporangia.
   b. Megasporophyll, sporangium, and bract. Remove sporophylls from strobili and determine the relations of the above structures. Construct a vertical sectional view of bract, megasporophyll, and megasporangium. Consult the text concerning the morphology of the spruce strobilus. Is it a simple strobilus like that of the lycopod or is it a branch system with bracts corresponding to regular leaves? To what do the cone scales correspond?
2. **Staminate strobili.**
   a. Gross parts. Have the staminate strobili the same parts, with a similar arrangement, as the ovuliferous strobili? Have they both bracts and sporophylls?

b. Sporangia. Are the microsporangia abaxial or adaxial? How many sporangia are there on a sporophyll? Determine the mode of dehiscence in mature sporangia. Is the abaxial position an advantage in the dissemination of spores? Note the growth in length of the internodes of the strobilus when the microspores are ready for dissemination.

c. Microspores. Study the structure of the microspores. How is it adapted to dissemination?

d. Drawings. Draw an abaxial view of a microsporophyll with its sporangia. Draw a microspore.

3. **Pollination, fertilization, and carpotropic movements.** If material is available, study young pine and spruce cones at the pollination stage.

a. Pollination. What is the position of the strobilus at this stage? What is the position of the sporophylls?

b. Fertilization. Compare the size and position of the strobili at pollination with that of similar strobili at the time of fertilization and seed-shedding. Note the changes in position of the strobili due to carpotropic movements after pollination is effected. Compare the pine and the spruce in these respects.

c. Make outline sketches to illustrate changes in the size and position of pine or spruce strobili at the pollination, fertilization, and fruiting stages.

GAMETOPHYTES

1. **Male gametophyte.** Study the structure of the microspore and of the male gametophyte from prepared slides.

a. The microspore. How does the microspore differ in structure from an ordinary cell? Note the character of the cell wall, nucleus, and cytoplasm. Draw a microspore in section.

b. Gametophyte. Study the structures within a germinated microspore. Do you find the two-celled male gametophyte? the generative cell? If possible, find specimens in which the generative cell has formed a stalk cell and a body cell.

c. Comparisons. Compare the above structures with the male gametophyte and antheridia of *Selaginella* and cycads. What structures have been lost? Why are the lost structures not necessary in pine or spruce? To what in the germinated microspore of *Selaginella* do the generative cell and the stalk cell of the spruce correspond?

d. Draw a germinated microspore and male gametophyte of the pine or spruce. Summarize answers to questions under *c.*

2. **Female gametophyte.** Study median long sections of megasporangia in which the female gametophyte has formed. Study the section with hand lens and low power, comparing it with similar sections of cycad megasporangia.

a. Megasporangium. What structures of the old megasporangium are found in the section you are studying? Are there integuments, a micropyle, and sporangial tissue proper? Do they have the same relation to each other as in the cycad? Is there a distinct pollen chamber?

b. Gametophyte. Study the gametophyte tissue, the archegonia, and the gametes. What is the nature of the gametophyte tissue? What is the structure of the archegonia? Have they protective wall cells consisting of neck and venter? How many of the usual central cells (namely, neck canal cells, ventral canal cells, and gamete cells) are there?

c. Comparisons. How does the gametophyte of the spruce compare with those of the cycads? Has there been any further reduction in the archegonia?

d. Draw your section and label its parts correctly. Draw a single archegonium enlarged. Label.

3. **The seed and embryo.**

a. Cut median long sections of seeds of pine or spruce which have been softened in water. Study the section of the seed which shows the embryo most plainly.

b. Seed structure. Compare the structure of the seed with that of the ovules just studied. What structures of the ovule remain in the seed? What structures are changed? From what did the embryo arise?

c. Embryo structure. Compare the structure of the embryo with that of seeds previously studied. Do you find hypocotyl and cotyledons?

d. Draw your section and label the parts of both seed and embryo.

4. **Seed germination.** Study seeds in process of germination and make sketches to illustrate these phenomena:

a. Exit of the embryo from the seed. What part of the embryo emerges from the seed first? Do any parts remain in the seed?

b. Exit of the embryo from the soil. How is this effected and by what parts of the embryo? Compare this stage with a similar stage in peas illustrated in Part I of the text.

c. Adjustment of the embryo to light and soil. Compare with peas as above.

d. Make appropriate drawings to illustrate *a*, *b*, *c*, above.

5. **Life history.** Write a graphical life history of the spruce, indicating the main stages of the gametophyte and sporophyte generations.

SECTION X. ANGIOSPERMS (DICOTYLEDONS)

SPOROPHYTE

Examine typical dicotyledons in the laboratory and in the field, and review previous work on dicotyledons such as beans, mandrake, locust, and elm. Determine as follows the distinctive characteristics of dicotyledons which distinguish them from *Pteridophyta* and gymnosperms.

1. **Habitat.** What is the prevailing habitat of dicotyledonous plants of your region? Be able to name some mesophytes, xerophytes, and hydrophytes among them. Is your region typical for the habitat of dicotyledons in the United States? Consult the text under Descriptive Terms for figures and the meaning of terms used below.
2. **Habit** (geranium and similar dicotyledons).
   a. Leaf form and venation.
   (1) Compare the leaves of dicotyledons with those of *Pteridophyta* and gymnosperms, including spruces and pines. Are the dicotyledons large leaved as a group? What terms describe the form, margin, apex, and base of the leaves you are examining? Consult Fig. 208 of text.
   (2) Hold a leaf toward the light and study the venation. Is it pinnately or palmately veined? Do the veins end free in the margin (open venation) or are they united (closed venation)? See text, p. 415.
   (3) *Structure.* Review the structure of leaves in Chapter VI of the text in connection with Fig. 208.
3. **Anatomy** (herbaceous type, for example, geranium). Review the structure of herbaceous stems in Part I of

the text. Cut thin transverse sections of young and mature portions of stems of any cultivated geranium or of a similar herbaceous stem.

a. General features. Do the stem sections of the geranium correspond to the summary of the herbaceous stem structure of *Salvia*? Do you find tissue layers in the stem sections of geranium not present in *Salvia*? If so, what are they and in what main tissue zone do they occur, epidermis, cortex, vascular cylinder, or pith?

b. Secondary growth by cambiums. Compare transverse sections cut from young and mature portions of the stem of a geranium. What differences do you find between the young and the mature stem sections? Locate both the cork and the vascular cambiums, and the secondary tissues produced by them. Does the geranium plant produce corky bark? Examine both the sections and the surface of old portions of geranium plants concerning this point.

c. Leaf gaps and leaf traces. Study sections cut through a node or just below it. Do you find interruptions, or gaps, in the vascular cylinder where the leaf trace is given off? Large branch gaps may also be found, caused by an outgoing branch. Do you think that the irregular contour of the vascular ring is caused in part by leaf gaps and branch gaps?

d. Tissues of the vascular ring. Compare these with those of the spruce just studied. Do you find wood rays? annual-growth rings? wood parenchyma? Compare the ducts with the tracheids of spruce.

e. Storage tissues of the geranium stem. Determine the places where starch is stored in sections treated with iodine.

f. Drawings.

(1) Construct outline drawings of sectors of the young and old stems of geranium.

(2) Detail the cork cambium and its products.

(3) Detail a small portion of the vascular cylinder of a section of the older portion of the stem.

g. Long sections. If long sections of geranium are available, study the tissue of the xylem, noting especially the structure of the ducts. Draw spiral and dotted ducts and adjacent tissues.

SUMMARY

Summarize the structure of the geranium stem, modifying the summary given for *Salvia* (p. 108 of text), as you think it should be, to characterize the primary structure and secondary growth of a geranium stem.

WOODY TYPE (ANATOMY)

1. Review the work previously done on the structure and growth of trees in Part I of the text (Fig. 55 and discussion).

a. Comparisons. In what respects is the woody dicotyledon better equipped for conducting water and for storing food than the spruces and pines? In what respects does it differ from the herbaceous dicotyledon?

b. Summarize the distinctive features of the woody dicotyledon which characterize it as the most highly organized living plant. How is it adapted structurally to perform the functions of support, storage, and conduction? Where are the supporting, storage, and conducting tissues located in trees and shrubs? How do they differ in this respect from herbs like *Salvia* and geranium?

REPRODUCTION

1. **The flower and its parts.** Consult the text under reproduction and review the floral parts outlined in Part I. See also Descriptive Terms, at the beginning of Part III of the text.

   a. Structure of the flower. Determine which of the following terms apply to the flower you are studying. These terms are defined under Descriptive Terms, Part III of the text.

   (1) Is the flower you are studying hypogynous, perigynous, or epigynous? Is it perfect, imperfect, complete, or incomplete? Is it regular or irregular?

   (2) Are its parts arranged in spiral or cyclic form? How many parts are there in each set of protective and essential organs? What is the floral plan?

   (3) Construct a ground plan of the flower. Record the answers to questions asked above under (1) and (2).

   (4) *The flower as modified strobilus.* Bisect the flower and receptacle vertically, and note the arrangement of its parts on the receptacle. Does the flower correspond to a strobilus in the nature and arrangement of its parts? Compare with strobili of spruce. To what does the receptacle of the flower correspond in a strobilus? To what do the stamens, pistil, and perianth correspond? What are the ovules and the anthers morphologically? What fundamental differences exist between the strobili of the spruce and the flower you are examining? What new structures are found in flowers of the angiosperms as compared with the strobili of gymnosperms.

(5) *Summary.* Summarize in terms of axis, perianth, sporophylls, and sporangia the similarities and differences between the strobili of the spruce and the flower you are examining.

(6) *Definition.* Write a definition of a flower, considering the above facts concerning its morphology.

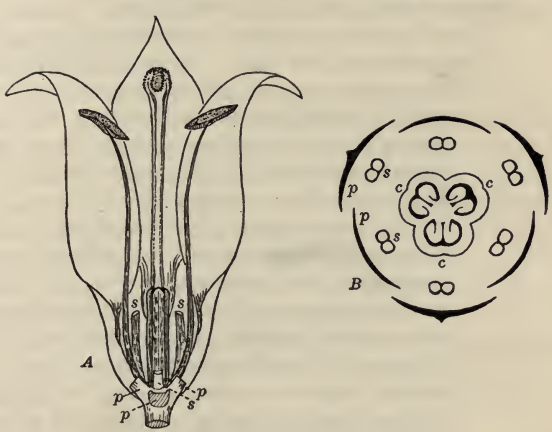

FIG. 25. The lily (*Lilium philadelphicum*)

A, dissected flower, showing the pistil and stamens: *p*, parts of the perianth which have been cut away; *s*, bases of stamens cut off. *B*, floral diagram: *p*, perianth, composed of two circles of similar and petal-like parts; *s*, stamens, likewise in two circles; section of ovule case (ovary) shown in the center, composed of three carpels (*c*) so united as to form three locules containing the ovules. From Bergen and Davis's "Principles of Botany"

(7) *Drawings.* Draw a vertical long section of the flower and label the parts with terms corresponding to those used for strobili of *Selaginella*, cycads, and spruce. Draw a ground plan of the flower (Fig. 217 of text).

b. Morphology and structure of stamens. Study the structure and mode of dehiscence of the anther. To what do the filament and anther correspond in the fern, in *Selaginella,* and in the spruce? Draw and label the parts of the stamen in terms of sporophyll and sporangia.

c. Microsporangia. Study transverse sections of anthers of the buttercup, mandrake, or a similar dicotyledon.

(1) *Sporogenesis.* How many microsporangia are seen in a transverse section of a young anther? Where is the sporophyll tissue and how is it differentiated? Is there a supplying vascular bundle and surrounding cortex and epidermis? Do the sporangia have the same general tissues as sporangia of ferns and microsporangia of *Selaginella,* cycads, and spruce? Are there wall cells, tapetum, and sporogenous cells, or spore mother cells, in each microsporangium of an anther? Note carefully the cell structure, including cytoplasm, nucleus, and chromatin, of the cells in each of these layers.

(2) *Drawing.* Outline the entire section. Detail the cellular structure of one microsporangium, showing the cells of the tapetum and the sporogenous cells magnified. Label correctly in terms usually applied to microsporophylls and microsporangia.

(3) *Spore dissemination.* Study transverse sections of mature anthers. What changes have occurred in the microsporangia during sporogenesis? How many microsporangia unite to form one anther sac? How is dehiscence provided for? Study the wall cells of the anther sacs. Is the layer beneath the epidermis structurally adapted for opening the anther sacs for spore dissemination? What

is the structure of these cells and how would they work in opening and closing the anther sacs?

(4) *Microspores.* Note the structure of the microspores or pollen grains. What is the nature of the outer wall, or extine? Outline one half of your section and detail the cell structure of wall cells and microspores on a part of the section. Label correctly.

d. Pistil and fruit.

(1) Study the pistil, noting particularly the nature and extent of the ovary, style, and stigmatic surface. Is each pistil simple or compound? Observe the megasporangium, or ovule, best seen in mature fruiting pistils. Compare the megasporophyll and sporangium with that of *Caltha* in the text.

(2) *Drawing.* Draw the pistil so as to show the stigmatic surface magnified and the relation of megasporophyll and megasporangium.

(3) *Fruit.* Make a drawing to illustrate the nature and parts of the fruit.

CAPSELLA (SHEPHERD'S PURSE)

Study the flower and inflorescence of the shepherd's purse as outlined above under Reproduction, 1, *a* (see Fig. 251, p. 400, of text). Make the following special study of pistil, megasporangium, megaspore, and embryo sporophyte. Consult the text discussion of *Capsella* (p. 345 of text, and Fig. 203).

1. Pistil.

a. Study young and mature pistils on the inflorescence of *Capsella* and determine the relation of stigma, style (if present), and ovary. Is the ovary simple or compound? How many placentæ are there and

how many rows of ovules or megasporangia? Determine this point by gross studies of the external features of the pistil, and by examining gross transverse sections of the pistil made with a scalpel or safety-razor blade.

b. Draw a lateral view of the pistil and a transverse section of the ovary. Label the parts in terms of megasporophylls (carpels) and megasporangia (ovules).

2. **Megasporangia, or ovules.** Dissect out a considerable number of ovules from both young and mature ovaries on a slide in a drop of water. Remove half of the ovules to a second slide and mount in a weak potash solution. Cover and study your two preparations to determine the following points:

a. Parts of the megasporangium, or ovule. Observe the funiculus, ovule proper, integuments, and micropyle. The embryo sac may often be seen in outline in specimens treated with potash. Compare the form of young and mature sporangia and note the gradual curvature of the entire sporangium and spore as the ovule matures.

b. Embryo sporophyte. The embryo can often be seen, in specimens bleached in potash, lying above the micropyle. It may be obtained free on the slide by slight pressure on the cover glass.

c. Drawings. Draw the ovules of *Capsella* to show as many of the above structures as you have been able to demonstrate, including the embryo and its parts. Name all parts correctly, consulting the text figure and the description of parts there represented.

3. **Female gametophyte and sporophyte of *Capsella*.** Study the female gametophyte, embryo sac, and sporophyte in prepared slides of ovaries of *Capsella*. Work out as

far as possible the cellular structure and relations of the following structures:

a. Megasporangia and female gametophyte.

(1) If sections are available, study the female gametophyte, consisting of the egg apparatus, polar nuclei, and antipodal cells. If such slides are not available, read the history of the development of the megaspores in angiosperms in the text and compare the history with that of megaspores in *Selaginella* and the spruce.

(2) *Drawing.* If sections are studied, draw and label the parts of the megasporangium, embryo sac, and gametophyte cells.

PART III. THE SPRING FLORA

SECTION XI. FIELD WORK (DICOTYLEDONS)

A. TREES AND SHRUBS

A METHOD OF RECORDING FIELD OBSERVATIONS

In the following outline for the study of trees in the field the same general plan is followed as in the description of typical species of willows, oaks, and maples in the text.

The directions should usually be followed for the study of one typical species in each family until the student is familiar with the methods employed in such work. Additional species should then be worked out by the students independently.

A convenient form for recording field observations and laboratory studies on trees and shrubs is submitted below in the form of what are termed Species Record and Family Record. If this plan is adopted, the record of the initial species studied in each family should be entered, as indicated in the outline, by checking, in the blank spaces following the terms employed, each term, or character, that applies to the species being studied. Outline sketches should also be made after such a plan as that indicated under Figs. 10, 11, and 12, pages 20–23, of text. See also the figure of the Carolina poplar (*Populus deltoides*) (Fig. 26).

It is convenient for class use to have the Species Record (p. 156) and the outline for Figures (p. 157) printed on two sides of a single field sheet. These field sheets can then be given to each member of the class for recording the results of field and laboratory work. The Family Record (p. 158) can be used in a similar manner, the outline for several species being printed on one sheet with the family characteristics at the end.

SPECIES RECORD

I. ANALYSIS

Family _____

Scientific name _____

Common name _____

II. CHARACTERISTICS

1. **Habitat:** { *a.* Local: mesophytic___xerophytic___hydrophytic___
   b. Geographical _____

2. **Habit:** erect_____spreading_____large_____small_____medium_____

   a. Bark: color, smooth, flaky, furrowed, etc.

   (1) Trunk _____

   (2) Branches _____

   b. Twigs: color_____stout_____slender_____smooth_____hairy_____

   c. Buds: size, color, smooth, hairy, resinous, etc.

   (1) Terminal _____

   (2) Lateral _____

   d. Leaf: form_____margin_____size_____phyllotaxy_____
   simple___compound___netted_____parallel_____pinnate_____
   palmate___leaf scar_____

   e. Lenticels: color_____shape_____size_____. Drawing

3. **Reproduction**

   a. Inflorescence: determinate_____indeterminate_____kind_____

   b. Flower characters: hypogynous___perigynous___epigynous___
   perfect___imperfect___regular___irregular_____complete_____
   incomplete_____

   c. Pollination features

   (1) Close___cross___odor___nectar_____color___irregular_____
   monœcious___dicœcious___polygamous___protandrous___
   protogynous_____heterostylous_____

   (2) Means: wind___insects___contact___gravity___water___

4. **Distinctive recognition characters** _____
   _____
   _____
   _____

5. **Commercial importance** _____
   _____
   _____
   _____
   _____

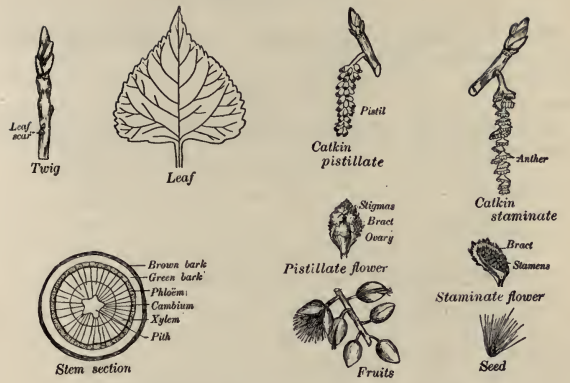

FIG. 26. Vegetative and reproductive parts of a poplar
Designed to indicate the method of recording observations on trees

FIGURES

1. **Twig, buds**
   Lenticels and scars
   Stem section

2. **Leaf characters**

3. **Inflorescence, flower**
   Long section of flower, pollination

4. **Fruit and seed**
   Fruit class_____
   Seed distribution_____

FAMILY RECORD

Fill in the analysis and the distinctive characteristics of each species of any given family under I and II.

Fill in the family characteristics common to all species observed under III.

Use habitat, habit, and reproduction as the basis for your characterization of the family.

I. Analysis

Family_____

Scientific name_____

Common name_____

II. Distinctive Characteristics

Habitat_____

_____

Habit_____

_____

_____

Reproduction_____

_____

_____

III. Family Characteristics

_____

_____

_____

_____

GYMNOSPERMS (SOFTWOOD TREES)

The Pine

1. Habitat.

a. What is the nature of the habitat of the pines of your region as regards soil, drainage, and climate? Do pines grow best on lowlands or on well-drained slopes and uplands? What is the distribution of pines in the United States? What is their natural habitat as regards soil and climate? Are they mesophytic or xerophytic in general habit? How do you explain the apparent discrepancy between habitat and habit in the pines? Consult the text, manuals, and assigned readings on the above points.

b. Summarize the above points in your notes under the following headings:

(1) Habitat: local_____geographical_____
(2) Habit: mesophytic_____xerophytic_____
(3) Discrepancy between habitat and habit_____

---

2. Habit.

a. Form and body plan of the pine tree.

Review the text discussion of the body plan and mode of growth of the pine tree in Part I of the text. Consult also Fig. 10. Be able to account for the erect conical form, the excurrent trunk, and the false whorls of branches of common pines. Why is the trunk excurrent? What determines the cone-like form of the entire tree? How do the false whorls arise? Is the entire leafage well exposed to light? What factors determine this light exposure? Is it due to the form of the tree, to tropisms of leaves and branches, or to other factors?

b. Summarize the above points under body plan, growth methods of buds and branches, and tropistic responses of leaves and branches.

c. Long and dwarf shoots.

Long shoots in pines are the main branches and twigs; dwarf shoots are the small structures from which the needle leaves arise in clusters of two, three, or five.

(1) Study long and dwarf shoots of pines in the field. Do the dwarf shoots arise in a spiral or cyclic manner from the long shoots? Study the naked portions of a twig where the scars of dwarf shoots show their former arrangement. Observe the scalelike leaves on long shoots. What is the arrangement of the scale leaves on the long and dwarf shoots? Do dwarf shoots arise from the axils of scale leaves like ordinary branches?

(2) *Buds and growth.* Determine the nature and position of buds on long shoots. Are there lateral buds? Do dwarf shoots arise from lateral buds? Determine the age of a terminal portion of a long shoot by the rings of bud-scale scars.

(3) Draw a small portion of a long shoot from which dwarf shoots have fallen, to show their arrangement on the long shoot and their relation to the scale leaves. Draw the terminal portion of a long shoot to show the shape and character of buds, dwarf shoots, and needle leaves. It is best not to draw more than one or two dwarf shoots on the terminal shoot.

d. Strobili, or cones (see Fig. 233, p. 379, of text).

(1) *Ovuliferous strobili.* Observe the position of the reproductive cones on single long shoots and on

the tree as a whole. Is their general distribution and their individual attitude (due to tropistic response) such as to facilitate the distribution of seeds? Search for the seeds. What adaptation have they for dissemination? What is the plan of arrangement of the cone scales on the cone axis? Does it correspond to the body plan of the tree?

(2) *Young strobili.* Do you find strobili of different ages on the pine? Note the position of young strobili. How long does it take pine cones to mature?

(3) *Staminate and ovulate strobili.* Do you find both staminate and ovulate strobili on the same tree? The staminate cones can only be found in late spring, since pollination occurs in pines about the first of June.

(4) Make simple sketches to illustrate the positions on the branches and the attitudes assumed by strobili of different ages and kinds.

ANGIOSPERMS (HARDWOOD TREES)

Field Studies

1. **Habitat.**

a. Local habitat. Study the conditions under which the species grows in the local habitat, including the soil, water supply, and drainage conditions. Which one of the following habitats does it occupy?

(1) *Mesophytic habitats.* Does it live in typical upland mesophytic conditions or is it found on lowlands such as flood plains, river banks, and the borders of lakes and ponds? Note that ornamental trees are frequently not growing in their natural habitat.

(2) *Xerophytic habitats.* Does it occupy exposed dry cliffs and hillsides, sandy regions, or mountain sides without adequate water supply? Is it found in marshes or swamps which are physiologically dry on account of the condition of the bog water?

(3) *Hydrophytic habitat.* Does the species live in soil flooded or saturated with water?

b. Geographical habitat and distribution. Determine the natural habitat and distribution of the species on the American continent by means of manuals and maps. Consult maps and descriptions in Hough's "Handbook of North American Trees" if this work is available. Consult the text, Fig. 223, and the discussion of trees and shrubs.

2. **Habit.**

a. Is the species being studied mesophytic, xerophytic, hydrophytic, or tropophytic in habit?

b. Size and form. Is it large or small as compared with other trees in the region? Is it erect or spreading in habit? Is there a single excurrent trunk or does the trunk divide above into two or more secondary axes?

c. Body plan and development. Review the text discussion in Part I on the development of trees and its relation to body plan, bud growth, and pruning in the spruce and elm. See Fig. 11 of text.

d. Study the relation of the following four main factors, which determine the form of a tree, to the ultimate form assumed by the species you are observing, as indicated below:

(1) *Body plan.* Is the species you are studying cyclic or spiral in leaf and bud arrangement? If spiral, is the phyllotaxy $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, or a higher fraction?

(2) *Buds and growth.* Is there a main terminal bud, as in the pine, producing a single excurrent trunk, or is the main terminal bud superseded by one or more laterals which produce a subdivision of the trunk above? How many lateral buds produce strong shoots each season? Consult the growths of the last four or five years on the terminal portions of branches. How many buds remain latent or produce weak lateral twigs each season?

(3) *Pruning effects.* Determine the effect of natural and artificial pruning on the form of the tree. Do small unsuccessful twigs or shoots continue to form a part of the crown of the tree or is the crown composed wholly of the more vigorous shoots of past seasons?

(4) *Adjustments to the environment by tropisms.* Observe the position of branches in the upper, middle, and lower thirds of the crown. Is the form of the branches and their position with reference to the main or to the secondary axes different in the above portions of the crown? Is the response mainly to light or to gravity? Do the positions assumed by the branches secure a better light exposure for the leaves and a better position for the dissemination of fruits and seeds?

e. Bark. Compare the bark on the main trunk and its branches. Is there a marked difference in color, and in smoothness or roughness, between the bark on the branches of the upper and middle portions of the crown and that of the main trunk and its larger subdivisions? Is the difference such as to form a distinctive characteristic of the species under

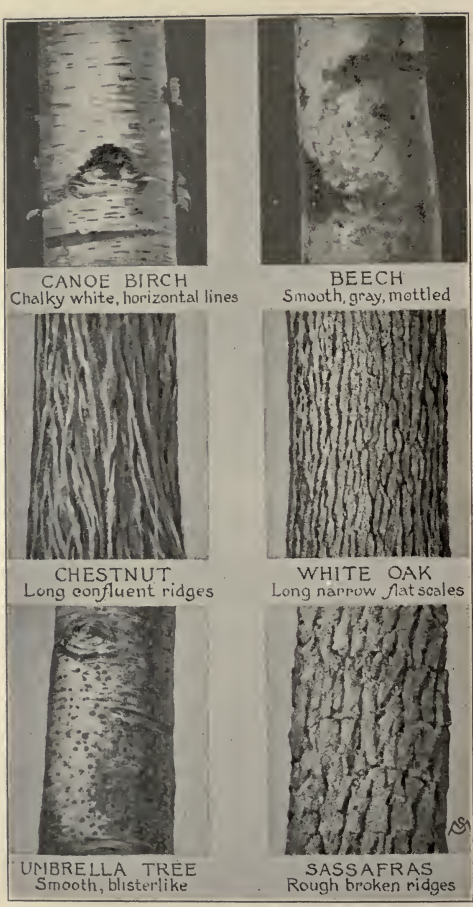

FIG. 27. Three kinds of bark — smooth, ridged, and scaly. (After Mathews)

examination? Is the bark on the trunk rough or smooth, furrowed or flaky, corky or indurated, in texture?

f. Leaves and the light relation. Observe the form and texture of the leaves and their arrangement with reference to light. Have they distinct differences in form and arrangement which facilitate lighting by the sun? Have they distinct organs or methods for tropistic response which expose them favorably to light? Do they form mosaics?

g. Outline sketch. Draw an outline sketch, similar to the figures of the elm in Part I, to illustrate the above points relative to habit. For the first studies the student may well draw a series of figures, similar to Fig. 11, *a–f*, to show the relation of body plan, growth, and pruning to the ultimate form and leaf exposure of the tree.

3. **Reproduction.** Study the inflorescence, flowers, fruits, and seeds of the species you are observing, as follows:

a. Inflorescence. Are the flowers solitary in the axils of leaves or are they borne in clusters? In the latter case determine the kind and the general structure of the inflorescence. Consult the text description of the kinds of inflorescence under Descriptive Terms.

b. Flowers. Study the structure, floral plan, and pollination features of the flowers under the following headings, determining which terms are applicable to the species being studied. Consult the text under Descriptive Terms.

(1) *Structure.* Are the flowers complete or incomplete, perfect or imperfect, regular or irregular in form? Are they hypogynous, perigynous, or epigynous in the relation of their floral parts?

(2) *Floral plan.* Are the flowers spiral or cyclic in the arrangement of their parts on the receptacle? Are they on the plan of 3, 4, or 5?

(3) *Pollination features.* Study the adaptations, if any, which the flowers possess for securing pollination, as well as the means or agents by which pollination is secured. Be able to designate those of the following terms which apply to the flowers under observation. Are they close-pollinating, cross-pollinating, or self-pollinating? Have they color, odor, nectar, or any other attractive features for securing insect pollination; that is, are they entomophilous? Are they adapted for wind pollination; that is, are they anemophilous? If so, be able to state the adaptation.

c. Fruit and seed. Study the nature of the fruit and its origin from the pistil. Are there special devices for seed and fruit dissemination? Do you know of any wild tract which has been seeded by fruits disseminated from near or distant trees of the species you are studying? In what places in your region are trees most successful in producing offspring by seed dissemination? In what places in other regions? Considering the large number of seeds produced by each tree, why are trees not more abundant?

d. Drawings. Make sketches to illustrate the structure, floral plan, and pollination features of the flower. Draw the fruits and label all parts correctly. These drawings can be made separately or with other drawings of the species, as in the poplar, on the Species Record.

4. **Anatomy.** Cut gross transverse sections of twigs or small branches. Observe the nature of the wood, phloëm, and bark.

a. Is the wood porous or dense? ring porous (with pores in the spring wood) or diffuse porous (with pores in both spring and summer wood)? Is the wood hard or soft? Do you think it would be commercially valuable? Draw. See drawings of the poplar for a model.

b. Commercial importance. Find out if possible the commercial importance of the wood in the species being studied. See figures and discussions in the text on the above points.

5. **Distinctive recognition characters.** What distinctive characters would enable you to recognize the tree you are studying in the field? Are there distinctive characters of the species other than gross external ones? Summarize the distinctive characters under the record of results.
6. **Analysis.** Analyze the species, to determine the family to which it belongs and the scientific and common species names. Record the family, genus, and species on the Species Record.

B. HERBACEOUS DICOTYLEDONS

A METHOD OF RECORDING FIELD OBSERVATIONS

The method submitted below of recording field observations for herbaceous plants is similar to that indicated for trees and shrubs. The plan may be followed for a part of the field work if desired, until the student is familiar with methods of observing and recording results. It should not be carried to the point of becoming mechanical. After the first detailed studies have been recorded on the Species Record form, teachers may prefer to use the Family Record exclusively. Loose-leaf sheets for species and family records are convenient and are used by the author in field work. These can be printed by a local printer from the outlines in these exercises.

SPECIES RECORD

I. ANALYSIS

Family_____

Scientific name_____

Common name_____Locality_____

II. CHARACTERISTICS: monocotyledon_____dicotyledon_____

1. **Habitat:** mesophytic_____xerophytic_____hydrophytic_____

2. **Habit:** mesophyte_____xerophyte_____hydrophyte_____

a. Stem: caulescent___branching___height_____acaulescent___
erect____horizontal____prostrate____climbing____rhizome____
bulb___corm___tuber___
Tropisms: pro_____dia_____apo_____

b. Leaves: large____small____medium____simple____compound____
(1) Venation: netted_____parallel_____pinnate_____palmate_____
(2) Position: radical___cauline___spiral___cyclic___decussate____
(3) Orientation: horizontal___vertical___oblique___rosette____
mosaics_____
(4) Light tropisms: pro_____dia_____apo_____

c. Roots: primary___lateral___fibrous___fleshy___surface___deep___
Gravity tropisms: pro_____dia_____apo_____

3. **Reproduction**

a. Inflorescence: solitary_____determinate_____indeterminate_____
kind_____

b. Flower characters: hypogynous____perigynous____epigynous____
perfect____imperfect____regular____irregular____

c. Pollination features
(1) Cross: odor____nectar____color____irregular____unisexual____
(2) Close: odor____nectar____color____regular____bisexual____
(3) Special features: protandry___protogyny___heterostyly____
(4) Means: wind____insects____contact____gravity____water____

4. **Distinctive characters**

_____
_____
_____
_____

FIGURES

1. **Stem, root, leaf**
   Habit and tropisms

2. **Stem section**
   Epidermis, cortex, vascular cylinder, stem, pith

3. **Inflorescence and flower**
   Long sections and ground plan
   Pollination features

   Detail: anther dehiscence, carpels, placentæ, ovules

4. **Fruit and seed**
   Fruit class_____
   Seed dispersal_____
   _____

FAMILY RECORD

Fill in the analysis and the distinctive characteristics of each species of any given family under I and II.

Fill in the family characteristics common to all species observed under III.

Use habitat, habit, and reproduction as the basis for your characterization of the family.

I. Analysis

Family_____

Scientific name_____

Common name_____

II. Distinctive Characteristics

Habitat_____

_____

Habit_____

_____

_____

Reproduction_____

_____

_____

III. Family Characteristics_____

_____

_____

_____

_____

RANUNCULACEAE (BUTTERCUP FAMILY)

Buttercup or Hepatica

Select one or more species of buttercups for field study.

1. **Habitat.** Determine the following facts concerning the habitat of buttercups:
   a. Soil, water supply, and drainage of their habitat at different seasons of the year.
   b. Plant associates. With what other plants are the buttercups associated? Does their association with these plants affect their relation to light, soil moisture, and soil food? Would these relations be different at different seasons of the year? Be able to explain the relation of this association to the spring flowering period of buttercups or hepaticas.
2. **Habit.** Use *Ranunculus fascicularis* for this study if it is available. Other species may be used. Study plants of *Ranunculus fascicularis* in the field; remove some plants from the soil with a trowel so as not to injure the root system, and observe as follows:
   a. Stem, roots, and leaves. Note the origin of the roots and leaves from the short (acaulescent) stem. Are the leaves cyclic or spiral in arrangement?
   b. Light relation. What position do the leaves assume with reference to light? Are they advantageously placed? Is this favorable placing of the leaves a resultant of both body plan and adjustment by tropisms, as in peas, dandelions, and trees studied earlier in the text? Be able to explain.
   c. Soil relation. Study the root system of *Ranunculus fascicularis.* What different kinds of roots do you find? What is the apparent function of each? At

what season do the different kinds of roots originate? Note the place of origin of each kind of root from the stem in young and mature plants. Do they originate at the same time and in the same manner? Save your specimen for a drawing in connection with the seasonal life of the buttercup.

d. Summarize the above facts relating to habitat and habit in your notes or on a Field Species Record.

3. **Reproduction.**

a. Flower scapes. Note the origin, and the position assumed by the flower scapes. What outside forces act as stimuli in orienting the flower scapes? Are they adjusted so as to expose the flowers and fruits properly for pollination and seed dissemination?

b. Flowers. What is the floral plan of the flowers under observation? What are the adaptations for pollination? Is the flower self-pollinating, close-pollinating, or cross-pollinating? Note any special devices for pollination.

c. Record your observations in the Species Record under *Pollination features.* Construct suitable drawings to show the pollinating device.

d. Fruit and seeds. To what class of fruits do the fruits of the plants you are observing belong? Consult the text, under Descriptive Terms in Part III, and Fig. 221. Record your results by drawings and terms giving the kind and class of the fruit.

4. **Seasonal life.** Are the buttercups and hepaticas annual, biennial, or perennial plants? What advantage is it to them that they flower in spring? Consider this point in connection with their plant associates and their habitat. Is their active food-building, like their reproductive functions, carried on mainly in the spring?

What is the function of the fleshy roots of *Ranunculus fascicularis* in its seasonal history? Construct figures corresponding to those of the white sweet clover (Fig. 65) and the dandelion (Fig. 24) in Part I of the text, to express the habit and the seasonal life of *Ranunculus fascicularis* or the other species observed. Summarize these facts in your notes or in the Species Record.

5. **Analysis.** Analyze one or more species of *Ranunculaceae.*

Floral Modifications in *Ranunculaceae*: Columbine (*Aquilegia*)

1. Compare the columbine (*Aquilegia*) with typical *Ranunculaceae* as regards habitat, habit, and reproduction, noting the variations in the columbine from buttercups and the marsh marigold.
2. **Reproduction.**
   a. Pollination. What floral arrangements facilitate pollination? Are the flowers protandrous or protogynous? Is self-pollination possible? Make a sketch to illustrate the method of pollination in *Aquilegia* and compare it with Fig. 250. Summarize the devices for securing cross-pollination which obtain in the columbine.
   b. Fruit and seed. Compare with that of the buttercup. What is the method of shedding and disseminating seed?

Violaceae

1. **Habitat and habit.** Study the habitat and habit of the *Violaceae* in the same manner as that outlined for the buttercup. What are their plant associates? Would violets have as good an opportunity for flowering and

setting seed in the summer and autumn as in the spring? Be able to explain this point.

2. **Seasonal life.**
   a. Compare the seasonal life of violets and buttercups. What are the principal activities of the violet plant in spring, autumn, summer, and winter? What portions of the plant are active at each season? Consult the text, Part I, on seasonal life.
   b. Summarize the above facts relating to the seasonal history of violets.
3. **Reproduction.** The flower and its modifications for securing pollination.
   a. Study the parts of the flower and their modifications. What modifications do you find in the perianth and the essential organs? Remove the parts of the perianth and observe their form and structure. Note the relation of the stamens to the perianth and to the pistil.
   b. Cut a transverse section across a flower in the region of the ovary. Study the section and construct a ground plan of the violet flower which will show the relation of the parts of the perianth and the essential organs.
   c. Pistil and stamens.
      (1) Dissect away all of the petals except the lower one with the spurlike nectary. Examine the stigma and anthers with a hand lens. Where is the stigmatic surface? How is it related to the anthers and to the canal leading to the nectary? Where is the pollen shed?
      (2) Bisect a flower longitudinally and study the above relation of pistil, stigma, and anthers to the nectary and the lower petal. Consult Fig. 253 of text and the discussion on pollination.

d. Pollination. How is pollination secured through the agency of visiting insects?

e. Drawing. Draw a median long section of the flower to show the relation of the floral parts which insure cross-pollination. Label accurately.

f. Summarize under the following headings the mechanisms of the violet which adapt it for cross-pollination.

(1) Perianth modifications.

(2) The relation of the pistil, stigma, and anthers.

(3) The anther tube and pollen shedding.

(4) The relation of a visiting insect to the flower in securing nectar.

4. **Analysis.** Analyze one or more species of violets, recording the family, scientific, and common name.

CRUCIFERAE

Study the habitat and habit of some of the important members of the cruciferous family.

1. **Habit.**

a. Stem and roots. What are the distinctive features of the stems and roots of the *Cruciferae* that you are studying? Are there characteristics which are unusual? What is the nature of the juice or sap?

b. Leaves. Observe any distinctive characteristics of leaves in members of the family under observation.

2. **Reproduction.**

a. Determine the nature of the inflorescence and the structure of the flower.

b. Drawings. Draw a ground plan of a flower of some one of the *Cruciferae.* Draw a median long section of a flower to show the relation of the perianth, stamens, and pistil.

c. Pollination.

1. What are the special devices for securing pollination? To determine this point study flowers of different ages and note the relation of the different lengths of stamens to the stigmatic surface. Does this relation change as the flower matures?
2. Construct outline drawings to illustrate any devices for self-pollination, close-pollination, or cross-pollination which you discover.

d. Fruit and seed. Study and classify fruits on one or more species of the *Cruciferae*. Construct a diagram of the fruit to show its method of dehiscence.

3. **Seasonal life.** Study the seasonal life of some of the more important cultivated species of the *Cruciferae* in the field and by consulting text references. See, for example, Bailey's "Encyclopedia of Horticulture," Robbins's "Botany of Crop Plants," and Sargent's "Plants and their Uses."

a. Are the members of the family mainly annuals, biennials, or perennials? How do the biennials and perennials pass the winter?

b. Construct a series of diagrams to illustrate the seasonal life of one important commercial variety of the *Cruciferae*. Consult the text, Part I, on the seasonal life of the bean, clover, and locust.

4. **Commercial importance.** Make a list of the more important species of *Cruciferae* and indicate the use of each species.
5. **Analysis.** Analyze species of the *Cruciferae*, recording the family, species, and common name.
6. **Distinctive characteristics.** Summarize under habit, reproduction, and seasonal life. The above data may be recorded on a Species Record or a Family Record sheet if desired.

LEGUMINOSAE

See Pollination devices in papilionaceous flowers in Part I of the text, and the seasonal history of the bean and the white sweet clover. See also previous laboratory work and drawings on the locust and sweet pea. Study the distinctive recognition characters of representative species of *Leguminosae* in the field and be able to summarize them under the following headings:

1. **Habit.**
   - *a. Stems.* Are the stems all herbaceous in character or are there some common trees and shrubs belonging to the family?
   - *b. Leaves.* What are the distinctive structural and physiological features of the leaves of all *Leguminosae* which distinguish them from other families of plants with which you are familiar? Study the leaves of several species and their reactions to light. Are they simple or compound? Have they special motor organs?
   - *c. Roots.* Dig up the root system of the common red clover, of the pea, or of the bean. Do you find enlargements on various parts of the root system in the form of nodules? These nodules contain the nitrogen-gathering bacteria which enable these plants to use free nitrogen from the soil. Observe also the extent of the root system as compared with the leaf system. Is the root surface exposed to the air?
2. **Reproduction.**
   - *a. Flowers.*
     - (1) *Structure.* Have the flowers of the family a common structure, floral plan, and form? Note any floral modifications from the usual type of the flowers of the family illustrated in the text.

(2) *Pollination.* Are all of the flowers of the family cross-pollinated? Compare the methods of pollination in peas, clovers, and vetches.

b. Fruits and seeds. Do you find all fruits in the family similar to that of the pea, bean, and locust?

c. Summary. Summarize the distinctive characteristics of the *Leguminosae* under the above headings and in the order indicated in the directions. This may be done on a Family Record sheet if desired.

3. **Economic importance.** Study species which are of economic and commercial importance in the family as indicated under the *Cruciferae.* List several important commercial species and the particular uses of each species.

SUPPLEMENTARY STUDY

Each student should be assigned some species of the *Leguminosae,* such as the common red clover, vetch, or lupine, for individual study and report. The report should include drawings to show the following structures:

1. **Habit.**

a. Leaves. Observe the mechanism for adjustments of leaves to light, including the position of leaves in the morning, at noon, and at night. Make a brief statement of the mechanism of movement in leaves with pulvini.

b. Roots. Drawings of roots with tubercles.

c. Reproduction. Observe and record the following facts relating to the flowers, fruits, and pollination:

(1) The structure of the flower and pollinating mechanisms.

(2) Fruit and methods of seed dispersal.

(3) A brief discussion of the pollinating mechanism and of seed dispersal in such a species as the common red clover.

d. Analysis. Analyze two or more species of *Leguminosae* and record as usual.

ROSACEAE

STRAWBERRY (*FRAGARIA*) OR *POTENTILLA* (CINQUEFOIL)

1. **Habit.**
   a. Observe the general habit of the strawberry, noting the relations of stem, leaves, and roots.
2. **Reproduction.**
   a. Vegetative reproduction. Study the origin of the runners, and their general morphology. Do they originate, like stems, from the axils of the leaves? Have they nodes, internodes, and leaves? How do the runners produce offspring?
   b. Construct a diagram to illustrate the origin, morphology, and mode of reproduction by runners.
   c. The flower. Study the floral plan and structure of the flower. Be able to construct a ground plan of a flower.
   d. Pollination features. Read the text on *Fragaria* and consult the figures. Determine the method of pollination in the species or variety that you are studying. Construct figures to illustrate the method of pollination observed.
   e. Flower and fruit.
      (1) To what class of fruits does the strawberry belong? What are its parts and how are they related to the similar parts of the flower? Bisect a fruit lengthwise and compare it with a similar section of the flower. Be able to name corresponding parts in the flower and the fruit.
      (2) *Drawings.* Draw a median vertical section of the flower and fruit of the strawberry and name the corresponding parts.

The Cultivated Apple (*Malus*)

1. **Habit.**
   - *a. Form and body plan.* Be able to account for the form and leaf display of the apple tree, as for the elm and pine in Part I of the text. Determine this on the basis of body plan, bud growth, pruning effects, and adjustments of leaves and branches by tropisms.
   - *b. Buds and fruit spurs.*
     (1) Where are the fruit-bearing branches (fruit spurs) located on the main branches of the tree? Search for bud-scale scars, and leaf and fruit scars on the short fruit spurs or spur shoots. The fruit scar is usually a large, circular scar surrounded by smaller scars representing the scars of undeveloped fruits in the same flower cluster. How many years old are the spur shoots that you are examining?
     (2) Draw a terminal shoot of an apple branch, indicating the position, form, and markings of the spur shoots.
2. **Reproduction.**
   - *a. Inflorescence.* To what class of inflorescence does that of the apple belong?
   - *b. Flower structure.* Is the flower epigynous, perigynous, or hypogynous? Determine the relations of receptacle, perianth, stamens, and pistil.
   - *c. Pollination.* Determine the method of pollination in the apple flower. Is the method of pollination of economic importance? Be able to explain this point.
   - *d. Flower and fruit.*
     (1) Study transverse and long sections of the fruit. What parts of the flower are represented in the fruit? What parts are lacking? What parts

have increased in size and what parts have become otherwise changed?

(2) *Drawings.* Draw a transverse and a vertical median section of the flower of the apple, magnified sufficiently to show clearly the parts of the ovary and the ovules.

(3) Discuss briefly the parts of the flower which enter into the formation of fruit, and the changes undergone during fruit formation.

3. **Reference readings.** Consult various texts concerning the history and reproduction of the cultivated strawberry and apple. Robbins's "Botany of Crop Plants" is particularly valuable as a reference on the above points. See also Bailey's "American Horticulture."

SUPPLEMENTARY STUDY

1. If time allows, the student should study the flowers and fruits of the wild rose, cherry, raspberry, and blackberry, in order to acquaint himself with the methods of fruit formation in these important fruit-bearing species.

2. **Commercial varieties.** Study and record important commercial species and varieties of the *Rosaceae*, as for the *Cruciferae* and *Leguminosae.*

COMPOSITAE

The Yarrow (*Achillea*)

Read the text discussion of the inflorescence, flowers, and fruits of the common yarrow and confirm the points there discussed.

1. **Inflorescence.** To what class of inflorescence does that of the yarrow belong? Bisect the inflorescence vertically and study its parts. What is the form of the axis of inflorescence? What structures make up the involucre?

To what structures do these parts of the involucre of the yarrow correspond in a raceme or spike? How are the flowers of the inflorescence differentiated? Is there any conceivable advantage in this differentiation? Does each separate flower spring from a separate bract? Compare the parts of the inflorescence of the yarrow with that of a raceme.

2. **Flowers.**
   a. Central tubular flowers.
      (1) Study these flowers with a hand lens and determine the relation of calyx, corolla, stamens, and pistil. Is there anything corresponding to a calyx?
      (2) Are the flowers hypogynous, perigynous, or epigynous? Are they perfect or imperfect? complete or incomplete? regular or irregular?
      (3) Note the bract subtending each flower.
   b. Outer ray flowers. What is the function of the ray flowers? Compare these with the central tubular flowers. Are the essential organs present? How is the corolla modified?
3. **Pollination.** Split the corolla of young and mature tubular flowers with dissecting needles so as to expose the stamen tube and style. Compare the young and old flowers as follows (consult the text figure):
   a. Note a stage where the upper portion of the style is still within the anther tube. Where are the stigmatic surfaces? Is the pollen being shed? Can it reach the stigma?
   b. Observe a slightly older stage. Are the stigmatic surfaces exposed? Can they be self-pollinated? Are the flowers of the yarrow protandrous or protogynous?

4. **Fruit and seed.** To what class of fruits does that of the yarrow belong? Is there any definite device for seed and fruit dispersal?
5. **Summary.** Summarize the distinctive features of the yarrow, as a representative of the *Compositae*, under the above headings; namely, inflorescence, flowers, pollination, and fruit. Give the distinctive features only.
6. **Analysis.** Ascertain the scientific name of the yarrow by means of a manual.

Dandelion (*Taraxacum*)

1. **Habit and adjustments by tropisms.**
   a. Study the plants of the dandelion in flower and determine the relations of its organs to each other and to the environment. Consult the text discussion (Part I) concerning the adjustments of the leaves, flowers, and fruits for photosynthesis, food absorption, pollination, and seed dispersal. Confirm these points by field observations.
2. **Reproduction.**
   a. Vegetative reproduction.
      (1) Dig up a number of plants of the dandelion. Is the stem simple or branched? Do you discover how a single plant may give rise to a group of offspring by vegetative reproduction?
      (2) Construct outline figures to illustrate what you find in this respect.
   b. Inflorescence and flowers.
      (1) Compare the general structural parts of the inflorescence and flower of the dandelion with that of the yarrow. In what respects are they similar? In what respects do they differ?

(2) Summarize the similarities and differences of the inflorescence and flowers which you have observed in comparing the dandelion with the yarrow.

(3) *Pollination.* Proceed as directed under the laboratory directions on the yarrow to find out the mechanism of pollination in the dandelion. Compare with the yarrow in this respect. Construct figures for the dandelion similar to those of the text on the yarrow.

c. Fruit and seed. Study the fruit and seed of the dandelion and compare them with the fruit and seed of the yarrow.

(1) What special device has the fruit of the dandelion for dispersal? What is the origin of the parachute of hairs? To what part of the flower do the hairs correspond?

(2) Construct a series of three figures to illustrate the development of the fruit in the dandelion, beginning with closed floral heads in which the flowers have been recently fertilized.

3. **Seasonal history.** Construct figures to illustrate the seasonal history of the dandelion. Is it annual, biennial, or perennial? By what means does it spread so rapidly in lawns and along roadsides? Study the relations of its leaves to the grass beneath them. State five reasons why the dandelion is so successful in gaining and holding a place for itself in lawns.

4. **Analysis.** Ascertain the species name of the dandelion by means of a manual.

SECTION XII. FIELD WORK (MONOCOTYLEDONS)

A. TRADESCANTIA, TULIP, AND OTHER MONOCOTYLEDONS

The most common and well-known monocotyledons include the common grasses, sedges, and cereal grains, different members of the lily family, palms, bananas, and bamboos. The student should consult illustrated manuals and texts in order to form a general idea of the habitat and habit of the monocotyledons. Examine also a number of species in the field and in the laboratory, as outlined below, in order to fix the main distinctive characteristics of monocotyledons. *Tradescantia* and the tulip may be taken as types for special examination.

1. **Habitat.** How many of the above-mentioned common monocotyledons are widespread or cosmopolitan in habitat? How many are restricted in habitat? Are most of these monocotyledons mesophytic, xerophytic, or hydrophytic in habitat and habit? Can you name common monocotyledons belonging to all three of the above habitats? Summarize the above facts in your notes.
2. **Habit.** Compare monocotyledons with dicotyledons in the following particulars of general habit and structure:

a. Leaves.

(1) *Form and venation.* What are the distinctive features of the leaves of monocotyledons in these respects? Note particularly whether monocotyledons have open or closed marginal venation.

(2) Study and draw leaves of one or more monocotyledons to illustrate the form and mode of venation characteristic of the group.

b. Stem.

(1) *Aërial and underground stems.* Do monocotyledons generally have aërial stems as well developed as dicotyledons? How is this in grasses and cereals, cultivated lilies, narcissus, tulips, onions, iris, palm? Do they have rhizomes, bulbs, and tubers? Study specimens and manuals to determine this point. Are the aërial stems of monocotyledons mostly flower-bearing stems or are they well-developed leafy stems? Are monocotyledons mostly herbs, trees, or shrubs? Compare with dicotyledons in this respect.

(2) Study and draw the underground and aërial stem or stems of one or more monocotyledons. Indicate nodes, internodes, buds, and annual increments of growth.

(3) *Anatomy.* Cut transverse sections of the aërial stem of some monocotyledon and observe the sections with low and high powers of the microscope. Are there the usual tissue areas characteristic of the stems of dicotyledons; namely, epidermis, cortex, and the vascular ring of phloëm, xylem, and pith? Is there a cambium present? How do monocotyledon stems increase in thickness? Draw your section in outline, naming the tissue layers and tissue groups as you think they should be labeled. Draw a single vascular bundle and label its skeletal and conducting tissues. Summarize the distinctive features of the anatomy of monocotyledons as for dicotyledons above. See

the discussion of the stem structure of monocotyledons in Part I of the text.

3. **Reproduction.**

a. The flower. Study the structure and floral plan of flowers of one or more monocotyledons.

(1) In what respects are these flowers like the flowers of dicotyledons already studied? In what respects, if any, are they different? Have the flowers of monocotyledons and dicotyledons the same number of floral members in a cycle? See your specimens and illustrated manuals.

(2) *Essential organs of the flower.* Compare the stamens with those of dicotyledons. Study the pistil of the tulip or of a similar monocotyledon. Cut transverse sections and observe the relation of megasporophylls or carpels which enter into the formation of a pistil in monocotyledons. Is the placenta central or parietal? Note the form and attachments of the ovules. Draw the section of the pistil and ovules greatly enlarged. Label.

(3) *Ground plan.* Construct a ground plan of a flower of a monocotyledon and compare it with the similar plan made of the flower of a dicotyledon. In what fundamental respect are the two different? In what respects are they alike?

b. Seeds and embryo. If available, study the seeds and embryos of typical monocotyledons, including a cereal, such as corn or wheat. In what respects do the seeds and embryos of typical monocotyledons differ from those of dicotyledons? Construct a drawing of a seed of a monocotyledon to show the relations of the embryo, endosperm, and seed coats.

4. **Summary and comparisons.** Summarize the contrasting characteristics of monocotyledons and dicotyledons under the following headings:
   a. Habit.
      (1) Leaves: form and venation.
      (2) Stem: general characters and anatomy.
      (3) Roots: general characters.
   b. Reproduction.
      (1) Floral plan.
      (2) Seed and embryo.

Consult the text discussion under the comparison of dicotyledons and monocotyledons.

B. SOLOMON'S SEAL (*POLYGONATUM*) OR FALSE SOLOMON'S SEAL (*SMILACINA*)

1. **Habitat.** Ascertain by field studies the natural habitat of such forms of monocotyledons as the Solomon's seal, in which there is a rhizome and an aërial stem. Are they typical mesophytes or are they tropophytes (plants which adjust themselves alternately to typical mesophytic conditions and to dry semixerophytic conditions)? What structural provisions have the true and false Solomon's seal for such environmental adjustment? Is this a common adjustment in monocotyledons with stems in the form of rhizomes or bulbs?
2. **Habit.**
   a. The rhizome, or underground stem.
      (1) Are there nodes and internodes? leaf scars and bud-scale scars? scars produced by previous aërial stems? Are there other evidences that the rhizome is a stem?
      (2) *Buds and growth.* What structures are produced each season by the growth of buds on the rhizome?

How many years of growth are represented in your specimen? Is the aërial stem a product of a terminal or of a lateral bud? How is the growth of the stem continued after the production of the annual aërial stem? Does the rhizome branch underground?

b. Aërial stem. Compare the general form and structure of the aërial stem and rhizome. Are there nodes, internodes, buds, and branches?

c. Leaves. Study the leaves and their venation. Compare their form and venation with that described in the text.

d. Drawing. Construct a drawing to illustrate the main structural features mentioned above.

3. **Anatomy.** Cut transverse sections of the underground and aërial stems and stain with iodine.

a. Compare the two sections as regards the disposition of the skeletal, storage, and vascular systems. What is the main function of the rhizome? of the aërial stem? Is the structure of each stem adapted for its work?

b. Construct outline sketches of each stem to illustrate the distribution of the three classes of tissues mentioned above.

4. **Reproduction.**

a. Inflorescence. Are the flowers solitary or do they form an inflorescence? If an inflorescence is present, to what class does it belong?

b. Flowers.

(1) *Structure and floral plan.* Compare the structure and floral plan of the flower that you are studying with that of a typical monocotyledon, like *Tradescantia*, described in the text. Is the flower perfect, complete, and regular?

(2) *Pollination features.* Ascertain whether the flowers are self-pollinating, close-pollinating, or cross-pollinating. Are there special devices for securing pollination?

(3) *Drawings.* Construct a ground plan of the flower and outline drawings of the flowers in long section to illustrate the relation of anthers and stigma at the time of pollination.

c. Fruit and seed. To what class does the fruit belong? Are there special devices for seed dissemination?

5. **Seasonal life.** Is the plant you are studying an annual, a biennial, or a perennial? What are the seasonal functions of the aërial stem and rhizome? Construct a series of figures to illustrate the seasonal life of *Polygonatum* or *Smilacina.*

6. **Analysis.** By means of a manual ascertain the scientific name of the species studied.

C. IRIDACEAE AND ARACEAE

1. **Habitat and habit.** Study one species of *Iris* and one of *Arum,* using the same general plan as that outlined above for *Polygonatum* and *Smilacina.* Be able to explain the seasonal life and environmental relations of each.

2. **Reproduction.** Consult the text explanations and discussion of *Iris* and jack-in-the-pulpit.

a. Floral plan. Determine the floral plan in each case.

b. Structure. Are the flowers hypogynous, perigynous, or epigynous? Are they complete, perfect, and regular? Distinguish between the parts of the perianth. Do you find stamens and pistil of the regular type characteristic of monocotyledons?

c. Pollination in Iris. Consult the text description and confirm the structural arrangements there explained concerning the pollinating mechanism in *Iris.*

d. Pollination in jack-in-the-pulpit. Be able to explain the special devices for pollination in jack-in-the-pulpit.

3. **Summary.** Summarize the method and the special mechanisms for securing cross-pollination in *Iris* and jack-in-the-pulpit.
4. **Seasonal history.** Be able to explain and illustrate the seasonal history of *Iris* and jack-in-the-pulpit.

D. GRAMINEAE

1. **Habitat and habit.** Follow the plan outlined above in the general directions for studying monocotyledons.
2. **Reproduction.** Study the reproductive structures of the common cultivated oat (*Avena*), using the text discussion and figures to assist you in understanding the inflorescence, flower, and fruit. Make appropriate drawings of inflorescence and flowers.
3. **Seasonal history.** Be able to illustrate the seasonal history of some common grass and explain the seasonal functions of its main organs.
4. **Economic importance.** Summarize the facts relating to the economic importance of the plants belonging to the grasses and the grass family (*Gramineae*).

SECTION XIII. PLANT ASSOCIATIONS

In a preliminary course in botany very little time is available for the study of ecology. A brief field study will, however, give the student a valuable insight into the social life of plants and their dynamic relation to the environment. The following studies may well be assigned early in the spring term and followed as the season advances:

1. **Nature and composition of plant associations.** Make a preliminary study of any area of soil ten or fifteen feet square covered with vegetation, as indicated in the following outline:

   a. Kind and number of species associated together in one area.

   (1) Count the number of different kinds of plants inhabiting the area under observation. Name as many of the species as possible and determine unknown species by consulting manuals.

   (2) Make the same determination for a similar area somewhat removed from the first in the same plant association. Do you find any considerable variation in the two portions of the same association? If so, account for the variation in number and kind of species occupying the two areas.

   b. Habitat and habit of associated plants.

   (1) Determine as far as possible the environmental factors which characterize the habitat under observation and their effect on plant growth.

The principal factors to be considered are sunshine, shade, relative humidity, temperature, and soil conditions. Determine also the nature of the soil as far as possible, taking into account the water content, amount of humus, acidity, mineral salts, etc.

c. Structure and seasonal life of associated plants.

(1) Are the plants inhabiting the area under consideration mesophytes, xerophytes, or hydrophytes? Are they annuals, biennials, or perennials in habit? Have they any special adaptations which fit them for life in the habitat under observation?

(2) What are the dominant species? Can you determine why they are dominant? Is their dominance due to structural adaptations of leaf, stem, or root? Is dominance due to vegetative or other means of rapid propagation and dissemination? Is it due in any measure to a perennial or biennial seasonal life?

d. Summary.

(1) Draw a chart to indicate the distribution and abundance of the three or four dominant species of the area examined. This may be done by using circles, squares, and triangles of different sizes to represent different species, or by using the initial letter of each species to represent the position of the species in the plotted area (see Fig. 288 of text).

(2) List the species found, indicating whether they are annuals, biennials, or perennials. Indicate also whether they are mesophytic, xerophytic, or hydrophytic in habit.

(3) Work out by means of outline diagrams the seasonal history of one or two dominant species of the habitat.

(4) Define a plant association. What are the most important considerations which determine the kind of dominant species composing the association you have just studied?

2. **Kinds of associations.** Study the vegetation on the margin of a pond, lake, or stream, including the aquatic plants, the plants of the shore, and those of the drier regions adjoining the shore.

a. Zonation. Do you note any regularity in the arrangement of definite types of plants in the water and along the shore? Are there definite associations of plants thus arranged? Is the arrangement sufficiently regular to constitute definite zones of vegetation? See the text and figures illustrating the nature of zonation.

b. Kind and number of species in each zone or association.

(1) What plants grow in the water? Are there floating and attached algæ or seed plants? What plants grow along the immediate shore line? Study the species in each zonelike association. Do you find any discrepancy between the habitat and the habit of plants in any given association? If so, explain.

(2) Determine the nature of the habitat and the environmental factors controlling the association of plants in each zone of vegetation under consideration. Observe the structural adaptations of the species in the various zones.

3. **Summary and conclusions.**

a. Draw an outline diagram of the shore line investigated and indicate by symbols (such as circles, squares, triangles, crosses, etc.) the different zones of vegetation and the number and kinds of plant associations found.

b. List the dominant species of each association and indicate whether they are annuals, perennials, biennials, mesophytes, xerophytes, or hydrophytes.

c. Discuss the relation of the habitat of each association observed to the habit of the species comprising the association.

d. Explain any discrepancy found between the habitat and the habit of plants in the shore associations studied.

4. **Origin of new associations.**

a. Shore-line associations. Do you find indications of migration, invasion, and succession in the shore-line associations? Are plants invading the mud or gravel of the immediate shore zone? If so, what kinds of plants are they, and from what place did they come? Are they species with special devices for dissemination? Are they found in the adjacent associations or are they migrants from distant locations? Have they any special adaptations for their new habitat? Do you see any evidence of succession, or the replacement of one association by another? Discuss in your notes the phenomena observed.

b. Denuded areas. Select an area from which the vegetation has been removed within a comparatively short period, as on a denuded bank, field, garden, or roadside.

(1) What plants are invading the area? Are they from the adjacent vegetation? What are the means by which these species originally migrated to the new home? Have they special adaptations for becoming established in the new habitat? Is there a definite relation between the habitat and the habit of the invading species?

(2) Discuss the above facts concerning the area being investigated.

INDEX

(References to illustrations are indicated by asterisks accompanying page numbers)

Achillea (yarrow), 181
Adjustment to environment, 19
Algæ, 75; general study of, 82
American elm, plan and development, 13, 116*
Anaphase, 37
Anatomy, of *Adiantum*, 116; of *Pteris aquilina*, 118
Angiosperms (dicotyledons), 143; sporophyte of, 143; reproduction of, 146; hardwood trees, 161
Anthers, 65
Apple, cultivated, 180
Araceae, 190
Aspergillus, 96
Aster, 9

Bacteria, 89, 91*
Bark, 41, 42; kinds of, 164*
Body plan, 3; of lilac, 3; spiral, 4*
Bryophyta, 103
Buds, section of, 5*; structure and growth of, 34
Buttercup, 171

Capsella, ovule and embryo, 67*; flower of, 149
Catnip, 9
Cell, and tissue differentiation, 23*; and cell division, 35
Cell division (mitosis), 35
Cell structure and growth, 31
Cells, growth of, 33*
Cellular structure, 22
Cell-wall thickening, 24*
Chlamydomonas, 76
Chloroplastids in *Elodea*, 30
Chromoplastids, 31
Chromosomes, 35
Cinquefoil (*Potentilla*), 179
Collenchyma, 24*
Columbine (*Aquilegia*), 173
Compositae, 181
Coniferales, 135
Cross-pollination, 70
Cruciferae, 175
Cycadales (cycads), 130
Cyclic plan of milkweed, 6*

Dandelion, 183
Dicotyledons (angiosperms), 143; stems of, 50, 51*; trees and shrubs, 155; herbaceous, 167

Ecological relations of plants, 63
Elm, American, 13, 16*
Elodea canadensis, 30
Equisetales, 123; sporophyte of, 123
Equisetum arvense, 125; life history of, 126
Experiments, on tropisms, 20; fermentation, 88; on bacteria, 89

False Solomon's seal, 188
Family record, trees, 157; herbs, 170
Fermentation experiments, 88
Filicales, 113; sporophyte, 113; asexual reproduction, 120; gametophyte, 121; life history of, 122
Flower, parts of, 64; of angiosperms, 146, 147*
Fragaria (strawberry), 179
Fucus vesiculosus, 83
Fungi, 86

Gramineae, 191
Growth, of root tips, 31; of root-tip cells, 33*
Gymnosperms, 130; softwood trees, 159

Hawthorn, bud of, 5*
Helianthus annuus, stem sections, 51*
Hepatica, 171

Hepaticae, 103
Herbaceous dicotyledons, 167
Herbaceous plants, plan of, 6*; body plan of, 6; buds of, 7
Herbaceous stems, dicotyledons, 50; monocotyledons, 52

Income and outgo, 8*
Iridaceae, 190
Iris, 190

Jack-in-the-pulpit, 190

Leaf, structure of, 53, 54*, 55*; veins of, 55*
Leguminosae, 177
Lichens, 101
Lilac, 3
Lilac mildew, 102
Lily, flower of, 147*
Liverworts, 103, 105*, 106*
Lycopodiales, 126
Lycopodium, 126

Marchantia, 105*, 106*
Metaphase, 36
Microsphaera alni, 102
Milkweed, cyclic plan of, 6*
Mitosis, 35
Mold, *Rhizopus*, 94; *Penicillium*, 96; *Aspergillus*, 96
Molds, general nature of, 92
Monocotyledons, 52; structure of, 52; field work, 185
Morning-glory, seed and seedling of, 19*
Motor organs, 19
Musci (mosses), 108
Mushrooms, 97

Nutrition and seasonal life, 61

Œdogonium, 81
Ovule of *Capsella*, 67*

Papilionaceous flowers, pollination of, 68; structure of, 69; cross-pollination, 70
Penicillium, 96
Photosynthesis, 57
Physiology, experiments in, 57
Pine, white, 10*; study of, 159
Pines, form of, 9
Pistil, 65
Plant associations, 192
Plastids, 30
Pollination, 68. *See also* Cross-pollination
Polygonatum (Solomon's seal), 188
Poplar, vegetative and reproductive parts of, 157
Potentilla (cinquefoil), 179
Prophase, 35
Protococcus, 75
Pteridophyta, 113
Pteris aquilina, anatomy of, 118
Puffballs, 99
Pulvini, 19

Ragweed, 9
Ranunculaceae (buttercup family), 171; floral modifications of, 173
Reproduction, 64
Respiration, 60
Rhizopus, 94
Ricciocarpus, 107
Roots, structure of, 53
Root-tip cells, 26
Rosaceae, 179

Seasonal life and nutrition, 61
Seed and seedlings, morning-glory, 19*
Selaginella, 127; sporophyte of, 127
Selaginella martensii, 128*
Shepherd's purse, 149
Smilacina (false Solomon's seal), 188
Smuts, 100
Solomon's seal (*Polygonatum*), 188
Species record, trees, 156; herbs, 168
Spindle, 36
Spirogyra, 77
Spruce, anatomy of, 136; asexual reproduction of, 139; gametophyte of, 141
Spruce and pine, 135; sporophyte, 135
Spruces, form of, 9
Stamen hairs of *Tradescantia*, 27
Strawberry, 179

Telophase, 37
Thallophytes, 75
Tradescantia, stamen hairs of, 27
Transpiration, 61
Tree, structure and growth of, 44*
Trees, spruces and pines, 9; and shrubs, 155

Vegetable fibers, 25*
Violaceae, 173

Water ascent, 62, 71
Wheat, kernel and section of, 66*
Woody stems, anatomy, 41; microscopic structure, 45
Wound, healing of, 46*

Yarrow (*Achillea*), 181
Yeast, 86, 87*

Zamia, gametophyte of, 133

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